HELSINKI UNIVERSITY OF TECHNOLOGY
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QUALITY OF PROJECT SCHEDULES IN INDUSTRIAL PROJECTS

Thesis submitted in partial fulfilment of the requirements for the degree of Master of Science in Engineering

Espoo, 29 April 2009

Supervisor: Professor Karlos Artto
Instructor: Ph.D. Kalle Kähkönen

HELSINKI UNIVERSITY OF TECHNOLOGY ABSTRACT OF THE MASTER´S THESIS
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A realistic schedule is often defined as a critical success factor in project management research. Project scheduling methodology has been studied widely, and various tools have been developed for accurate scheduling. Despite the vast academic and operational development effort, modelling project duration with schedules in a realistic way remains difficult. The prevailing method of using previous similar project schedules often includes powerful assumptions about the schedule applicability. Furthermore, the lack of analytic models and tools for schedule evaluation prevents the pre-project estimation of schedule quality.

The purpose of this study was to review the current literature on project scheduling research and determine methods to evaluate the quality of composed schedules. In addition, the study explored the use of software-based scheduling tools and considered the feasibility of one particular computer program intended for the analysis of schedule quality.

The research was conducted by first reviewing the academic literature on project scheduling and its history. Despite the extensive literature on the subject, research focused on the evaluation of schedule quality was scarce. Software-based Planalyzer methodology was chosen for the analysis of the research because that tool is designed for evaluating complex structures of project schedules. Finally, based on the previous findings, a framework containing quality criteria was proposed for the evaluation of schedules.

The empirical part included four company cases of scheduling practices in industrial companies delivering complex global projects. Information obtained through interviews showed current scheduling practices and gave an insight on how the quality of schedules is understood in case companies. The proposed framework and Planalyzer method was applied in examining the case projects and scheduling methodologies. Based on the empirical findings, the framework was further refined to fit the purposes of quality evaluation. A checklist was also composed, which further helps to shift the focus onto project scheduling pitfalls. The proposed framework and checklist can be utilized to develop the quality of schedules to such a level that they can be adapted for software-based analysis.

The findings in the context of the study were that the quality of project schedules is affected by many factors that are difficult to include into schedules. Although scheduling is perceived as challenging, the use of advanced scheduling procedures remains non-existent. Sophisticated or time consuming methodologies have not been transferred from academic research into practices of project management. The findings of this study support the straightforward use of the proposed framework and checklist in the development and evaluation of schedule quality. The findings of the study can be applied in a variety of industries, though the often detailed and intertwined aspects of specialized projects should be recognized in application.

Keywords: Project Schedule, Scheduling, Schedule Quality, Schedule Evaluation, Scheduling Software, MS Project add-on, Planalyzer	**Publishing language:** English

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Realistinen aikataulu on määritelty monissa tutkimuksissa projektien kriittiseksi menestystekijäksi. Projektiaikataulutusta on tutkittu laajalti ja siihen on kehitetty mittava määrä menetelmiä ja työkaluja, mutta tästä huolimatta aikatauluilla on vaikea kuvata realistisesti projektien kestoa. Vaikka aikataulujen merkitys on tiedostettu projektinhallinnassa, analyyttiset mallit ja työkalut niiden laadun arvioimiseksi puuttuvat. Yleensä aikataulut muokataan vanhojen aikataulujen pohjalta ja oletuksena on, että aikataulutusprosessin mukaan laaditut aikataulut ovat toteuttamiskelpoisia, mutta niiden laadusta ei voida varmistua ennen kuin projekti on jo toteutusvaiheessa.

Tutkimuksen tavoitteena oli selvittää olemassa olevia aikataulutuskäytäntöjä ja löytää keinoja laadittujen aikataulujen laadun arviointiin. Lisäksi työssä kartoitettiin aikataulutukseen suunnattujen tietokonesovellusten käyttöä ja yhtenä tavoitteena oli selvittää erään aikataulujen arviointiin suunnatun ohjelman sovellusmahdollisuudet sekä yleispätevyys.

Tämä tutkimus toteutettiin suorittamalla aluksi kirjallisuustutkimus koskien projektiaikataulutusta ja sen historiaa. Laajasta aineistosta huolimatta kirjallisuus, joka käsittelee projektiaikataulujen laatua ja sen arviointia osoittautui lähes olemattomaksi. Ohjelmistoista perehdyttiin Planalyzer metodiikkaan, joka on suunnattu laajojen ja monimutkaisten aikataulujen rakenteen analysointiin ja sitä kautta laadun arviointiin. Kirjallisuuden pohjalta muodostettiin viitekehys projektin aikataulun laatukriteereille ja tätä hyödynnettiin empiriaosassa.

Tutkimuksen empiirinen osio perehtyi neljän globaaleja toimitusprojekteja toteuttavan teollisuusyrityksen aikataulutuskäytäntöihin haastattelemalla projektipäälliköitä ja aikatauluttajia. Esiteltyä ohjelmistoa sekä kehitettyä viitekehystä sovellettiin arvioitaessa tapausyritysten projektiaikatauluja ja aikataulutusmenetelmiä. Tuloksiin perustuen viitekehystä muokattiin edelleen paremmin arviointiin sopivaksi. Tämän lisäksi luotiin tarkastuslista, joka viitekehyksen ohella auttaa kiinnittämään huomioita aikatauluihin ja täten parantamaan niiden laatua. Hyödynnettäessä esitettyjä malleja pyritään aikataulut saattamaan tasolle, jolloin niitä voidaan analysoida myös ohjelmistosovelluksilla.

Työssä havaittiin, että aikataulutukseen vaikuttavat monet eri tekijät ja se koetaan haastavaksi, mutta silti kehittyneiden aikataulutusmenetelmien käyttö jokapäiväisessä projektitoiminnassa on harvinaista. Liian hienostuneet ja liikaa aikaa vaativat ratkaisut eivät ole siirtyneet tutkimuksista käytäntöön. Löydöksien pohjalta ehdotettua yksinkertaista viitekehystä ja tarkastuslistaa voidaan käyttää aikatauluja luotaessa ja niiden arvioimisessa sekä kehittämisessä laadukkaammiksi. Tutkimuksen havaintojen perusteella rakennettua mallia voidaan käyttää myös muiden toimialojen aikataulujen arviointiin, sillä aikataulutuksen periaatteet ovat yleisluontoisia. Kuitenkin tulee ottaa huomioon, että aikataulut sisältävät huomattavan määrän informaatiota, jonka arvioiminen ilman kyseisen projektin asiantuntemusta esitetyillä menetelmillä on haastavaa.

<table>
<tr><td>Avainsanat: Projektiaikataulu, Aikataulutus, Aikataulun laatu, Aikataulun arviointi, Aikataulutusohjelmisto, MS Project lisäosa</td><td>Julkaisukieli: Englanti</td></tr>
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Helsinki, April 2009

Mikko Hietala

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1 Introduction

1.1 Background and Motivation

A multitude of reasons affect the success of a project, but one reason for failure should not be unrealistic schedules. Every project struggles with various types of intervening variables which complicate planning. Preparing a project schedule is an easy endeavor compared to evaluating its quality.

Project scheduling has been identified in various studies as a major factor in predicting project success or failure (Fortune and White, 2006). This indicates the crucial role of schedules in project management. Since the mid-twentieth century a large part of research in project management has focused on project scheduling. The assumption has been that developing better scheduling techniques will help project management resulting in successful completion of projects. A number of authors have made efforts to find factors that influence project success or failure. Different frameworks are summarized by Belassi and Tukel (1996) in Appendix A.

Another issue emphasizing the importance of scheduling is that the formal planning efforts for cost and time in projects have focused mainly on time planning and to a lesser extent on costs and resource allocation (Laufer and Tucker, 1987). This is understandable because in today's fast-paced project environment, project owners want to get projects completed in the minimum amount of time to get a market advantage. Consequently, project contractors typically face liquidated damages for finishing late, thus no one gains from schedule overruns.

Currently, there are plenty of tools to help project managers manage all the data involved in developing and maintaining project plans. There are tools for task lists, resources, calendars and budgets, and tools that use Gantt charts, network diagrams, status reports and other tracking strategies. However, there are no easily implemented methods or tools for evaluating the schedule itself by measuring the quality, for determining whether the project is likely to be accomplished in the time allocated. (Hoglund, 2006; Zwikael and Globerson 2004)

Today, many project plans are done relying on similar plans of previous projects. This poses a problem if previous plans are not well-evaluated. Although the previous projects may have been completed well, a new project will most likely be different and the new project plan must be changed and re-evaluated. Often, project plans and time schedules are prepared in a systematic way using different kinds of analytical methods and estimations, but when the schedule is ready, there are no well-established methods or tools to evaluate it. There is a wide variety of project management literature about project planning, scheduling and control but not much on how to define the quality of schedules and how to evaluate them.

This study was conducted as a part of the Global Project Strategies II (GPS II) research programme. The research started in the later part of the year 2008 and was completed in April 2009.

1.2 Research Objectives, Questions, and Scope

The objective of this study is to understand the current state of project scheduling theory, project scheduling process, and usage of commercial scheduling software. Another objective of the study is to find analytical methods and tools to assess the quality of project schedules. To be able to realize this, it is necessary to define the criteria of schedule quality. Currently, there are many ways to build a time schedule but no methods or tools to evaluate the ready-made schedule. Different simulations can be performed, but the results do not describe much about the quality of the schedule. During the study, one interesting computer program for that purpose was discovered. In this study one will be familiarized with a method called Planalyzer and how it evaluates the quality of schedules. The schedules from the case companies will be analyzed with the software, and based on the results, the quality of the schedules will be evaluated. To understand the entire scheduling process it is important to find out what the currently used scheduling methods are. Historical insight to scheduling is provided in the beginning of the study to see how the field has developed during the years.

Research questions are formulated based on the objectives of the study. Three research questions have been set, and the first question is:

1. What are project scheduling practices?

The answer to the first question describes how the project schedules are created and what kinds of methods are used. The description will be based on the review of project management literature. The answers to this question contain elements to the definition of the second question:

2. How does one define the quality of project schedules?

The answer for the second question describes how to determine the quality of a project schedule.

The third question is:

3. How does one evaluate the quality of project schedules?

The third question is the key question and the answer will be found by analyzing the existing methods and adapting them to the definition of schedule quality. Based on the case project analyses and defined schedule quality criteria, a framework for schedule evaluation will be provided. In addition, how the Planalyzer method actually evaluates schedules will be studied. Planalyzer is used to analyze case schedules and applicable results are utilized in developing the evaluation framework further.

The scope of the study in the literature review will cover project planning and time management in a broader perspective. The empirical study will concentrate only on project schedules and how to evaluate their quality. Empirical study is restricted to major delivery (engineering, procurement, and construction) projects, e.g., power plants or paper mills. Material for case studies has been collected from companies which are delivering global and complex delivery projects. The decision to focus on major engineering delivery projects was mainly due to my previous experience in the same field.

1.3 Research Methods

The research was initiated with a literature review which gave an overview of the basics of the scheduling theory. The background information of project planning, history of scheduling, scheduling methods, and software tools is based on the literature. To conclude the literature review, a synthesis of current understanding of schedule evaluation is provided. Based on the findings in literature a framework for schedule evaluation is formulated.

The empirical case study included four case projects of different companies. The data were mainly gathered by interviewing the project managers and schedulers of case companies. Before the interviews, case companies provided schedules and case project documentation for analysis. The interviews included two parts: a semi-structured interview and a part where the schedules were pre-surveyed with company representatives. Additional information was requested from case companies by email and telephone conversations.

After the interviews the schedules were analyzed by using the literature-based framework and presented software tool. Case schedules of different projects were compared in the cross-case analysis. Finally, the data gathered from the empirical study were used to improve the framework.

1.4 Structure of the Study

The general structure of the study is presented in Figure 1. Chapter 1 serves as an introduction to the subject. Chapter 2 starts the literature review which examines project scheduling and gives an overview of the historical development of time management. In Chapter 3 the methods for evaluating schedules are presented long with a synthesis of the literature. Chapter 4 is the case and analysis section where the developed framework and presented software tool is used in schedule evaluation. Cross-case analysis is also provided and suggested models are presented. Finally, the thesis ends with conclusions and discussions where contributions, applicability, and reliability, as well as suggestions for further research are provided.

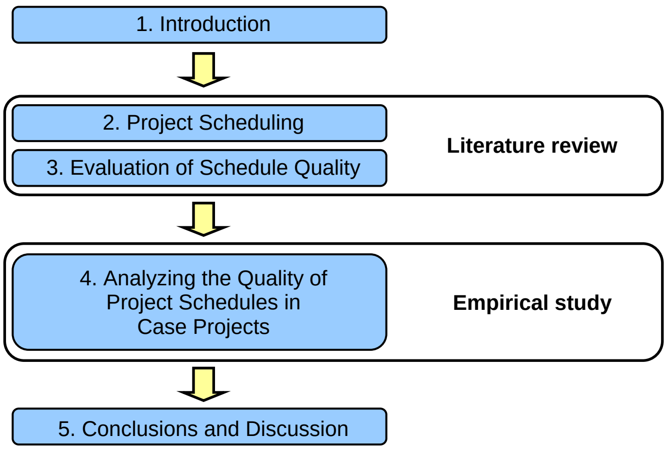


Figure 1 Structure of the study

1.5 Definitions

Glossary of special terminology and abbreviations used in the study can be found in Table 1.

Table 1 Glossary of special terms and abbreviations

Abbreviation / Term	Definition
ADM	Activity Diagramming Method
AOA	Activity-on-Arrow
AON	Activity-on-Node
CCPM	Critical Chain Project Management
CPM	Critical Path Method
EPC	Engineering, Procurement and Construction
EPCM	Engineering, Procurement and Construction Management
ERP	Enterprise Resource Planning
MS Project	Microsoft Project
PDM	Precedence Diagramming Method
PERT	Program Evaluation Review Technique
PMI	Project Management Institute
PMIS	Project Management Information System
PMS	Project Management System
WBS	Work Breakdown Structure

2 Project Scheduling

The literature review was conducted in order to create a theoretical base for this study. The review was started by searching existing research from well-known project management journals and books. In addition to general project management literature and journals, some of the findings came from the fields of construction management, production research, risk and operations management. The following sections describe the review in more detail.

2.1 Overview of the Literature Review

The literature review section is divided into two parts. The first part describes the project planning and scheduling in general, followed by a brief look at the history of project scheduling. Along with the history, the basic techniques which were developed in the past are presented. After this, the literature review is continued by presenting different types of schedules and how to use them in different phases of a project. In the end of the first section, the computer applications for project scheduling are reviewed. The second part concentrates on evaluation of schedule quality. Software tools for assessment are reviewed briefly and the Planalyzer method is presented in depth. Finally, the literature review ends with the synthesis.

The literature review was initiated by searching for sources citing project time management, scheduling and planning. These provided the basic information of planning and scheduling methods and tools. However, it was realized that this was a too generic way to search if the aim was to find out literature about how to analyze the quality of schedules. Search was continued with keywords including: project, schedule, evaluation, assessment, success, analysis, quality, software, tool, and technique. Some words were used as single search words, but many of them only in sound combinations of these words. In the majority of project management literature project scheduling is only discussed from the viewpoint of how to create a schedule and what kind of tools are needed. Project planning, including scheduling, was discussed extensively in construction management journals, but scheduling was not examined specifically, only as a part of the planning process. After quite extensive search it was discovered that the literature discussing the evaluation of the quality of schedules is scarce.

The review is based on published information, i.e. international journal papers, books and information sourced from the Internet. The literature material consists of several articles published in international journals of project and construction management and related books. The findings came mainly from well-known academic publications in the research area like “International Journal of Project Management”, “Project Management Journal” and “Construction Management and Economics”.

2.2 Project Planning

A project is considered a unique and temporary endeavour which has never been done before to create a product, service, or result (PMI, 2004). Therefore, it is difficult to know precisely at the initial planning phase what needs to be done in order to complete the project properly. The project planning process with different phases is presented in Figure 2 (Morris, 1994). The importance of the planning phase stands out relative to other phases in the project’s life cycle. (Dvir, 2003)

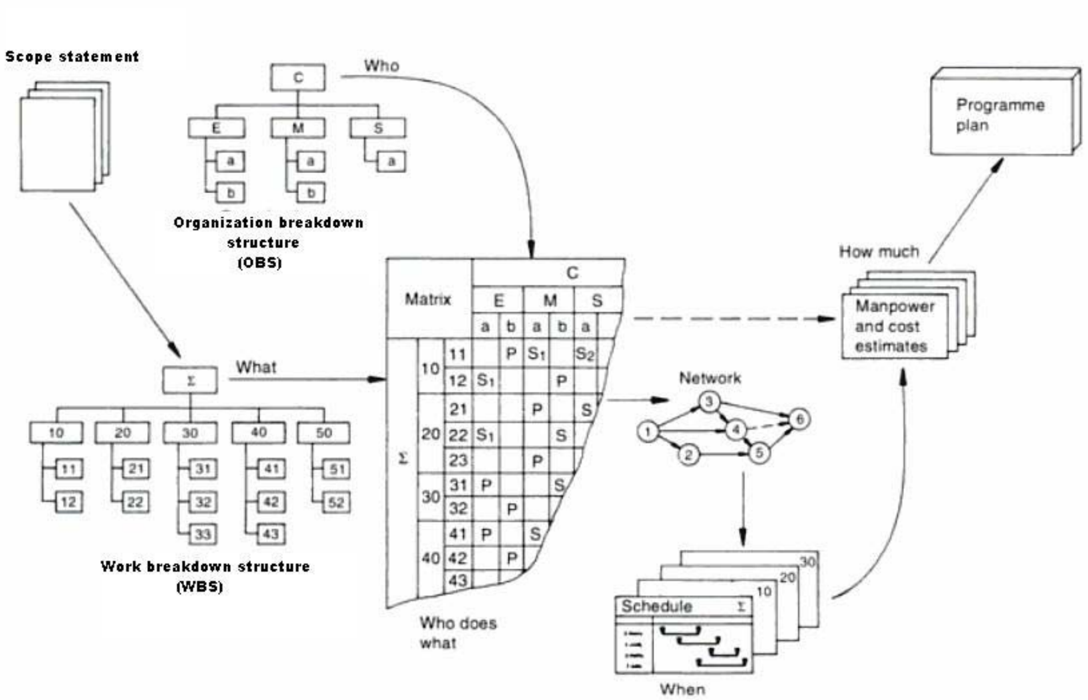


Figure 2 Project planning process (Morris, 1994)

When planning a project, one need to consider questions about what has to be done, how it has to be done, by whom, in what order, for how much, and by when. The planning process is an effective way to answer these questions. (Nicholas, 2004) Purposes of planning can be specified as the following.

- Setting the objectives and scope (end-items, desired results, time, cost, and performance targets)
- Defining and breaking down all required work activities and tasks to achieve objectives
- Defining a project organization to specify departments, subcontractors, and managers
- Preparing a project schedule to show the timing of works
- Indicating the amount and timing of resources and expenditures for work activities as budgets and resource plans
- Preparing a forecast for future projections of time, cost, and performance
- Providing tools for monitoring, reviewing and controlling project execution
- Improving optimization by analyzing more alternatives
- Utilizing the experience accumulated from previous projects in a systematic way

(Laufer et al., 1994 and Nicholas, 2004)

To answer the above questions, the project is initiated with the preparation of a formal plan. The purpose of the plan is to steer the project throughout the project's life cycle. (Nicholas, 2004)

The entire project is built upon the Work Breakdown Structure (WBS) framework. The scope defines the body for the project planning and, the WBS organizes the scope into a detailed hierarchical format. The scope and the WBS are then used as a base for formulating the project schedule. (Devaux, 1999)

The project scope statement ensures that the project includes all the work required to complete it successfully. It can be also specified what is not to be included within the project, to ensure clarity about expected outcomes. The scope statement describes objectives and deliverables of the project and it emphasizes the work associated to produce those deliverables. The scope statement communicates the needs, requirements, objectives, and outcomes to all project stakeholders and it enables and guides the project team to continue to more detailed project planning. (PMI, 2004 and Nicholas, 2004)

A scope plan works as a basis for future project decisions and creation of a WBS is the next step in the planning process. A WBS provides a logical and deliverable-oriented hierarchical structure of the work that project comprises. The WBS defines the total scope of the project and subdivides the project work into smaller pieces of work. At the lowest level of the WBS are work packages which can be scheduled, cost estimated and controlled. Organizational Breakdown Structure (OBS) is strongly connected to the WBS and it defines which organizational groups are responsible for different parts of the WBS. The WBS and the OBS can be combined in a responsibility matrix which indicates who is responsible for what, as can be seen in Figure 2 (PMI, 2004 and Morris, 1994)

2.2.1 Scheduling Process

In this section issues concerning project planning and scheduling process are presented. The next section will describe the history and fundamental scheduling techniques used as well as some special methods to address specific circumstances or problems. Usually, project planning is a wider concept which includes scheduling and in many cases scheduling is seen as a major part of the planning process. Thus, implications can be applied and realized to project scheduling.

The purpose of scheduling is generally defined as to provide a plan or roadmap that presents how and when the project will deliver the products defined in the scope of the project. Scheduling is one of the basic requirements of project planning and its main objective is to establish the time required for a project. (PMI, 2007)

A schedule supports arranging project tasks to assigned dates as well as to match the funds, resources of equipment, materials and labor with tasks of project work over time. By the established coordination, the scheduling can eliminate problems and facilitate the timely completion of a project. The schedule also works as an important document to record all activities and to analyze time extensions. (Hendrickson, 2008 and PMI, 2007)

In the development of a project schedule, it is common to decide which is emphasized, either cost control, or schedule control. When selecting schedule control, the scheduling of work tasks is critical and it is emphasized in the planning process. (Hendrickson, 2008) In most project companies the primary focus is on time planning while resource allocation and its cash-flow implications do not get that much attention. Scheduling gets excessive attention because of the high degree of interdependency between the timing and duration of a project. The management's ability to affect time goals is better than to affect cost or quality goals. (Laufer and Tucker, 1987) Traditional scheduling processes emphasize the maintenance of task precedence (resulting in critical path type scheduling) or efficient use of resources (resulting in job shop scheduling). (Hendrickson, 2008) This study mainly focuses on industrial delivery projects where task precedence gets the main attention. The consideration of both cost and scheduling makes things even more complicated. However, this study concentrates only on schedule orientation.

The typical planning process is presented in Figure 3 and it includes five phases (Laufer and Tucker, 1987).

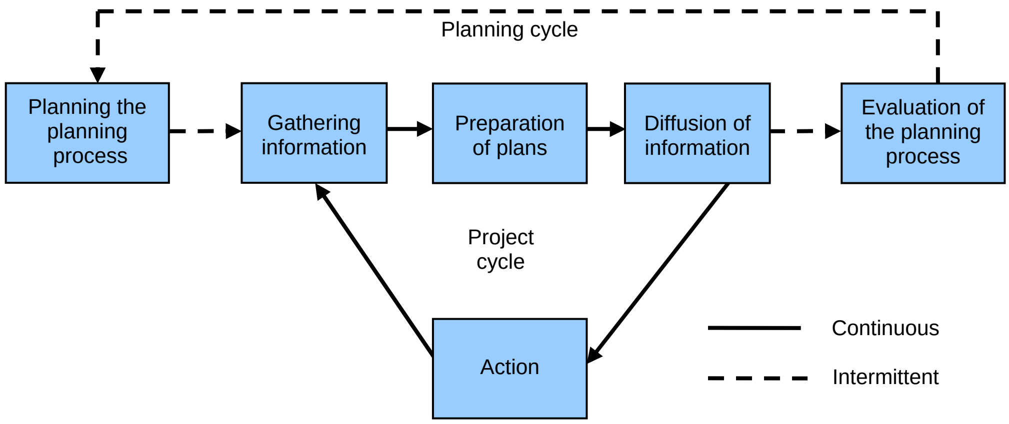


Figure 3 Planning process (Laufer and Tucker, 1987)

Laufer and Tucker (1987) have pointed out that the planning process includes some problems. In practice, the first and the last of the phases are neglected due to non-existence. Preparation of plans and schedules receives the most and sometimes only attention. Often, plans are presented badly with information which is too complex. The final evaluation of planning effectiveness is difficult to accomplish. Output measures are problematic because the results not only depend on the quality of planning but also on the quality of project management and many other environmental factors.

Project scheduling itself can be seen as a part of the planning process presented in Figure 3. It is mainly placed in the boxes of information gathering, preparation of plans, and diffusion of information. It can be noted that the first and the last phases are rare in scheduling as well. The process of project scheduling is usually divided into different phases which are indicated in Figure 4. The process includes the following steps.

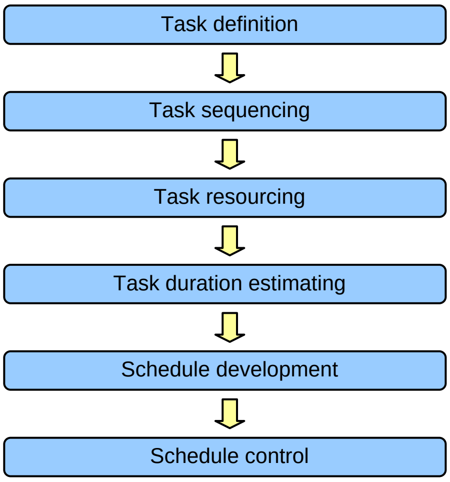


Figure 4 Scheduling process

The definition of work tasks includes identifying schedule activities that need to be accomplished to produce the deliverables of a project. Sequencing of tasks identifies the dependencies and interactions between schedule tasks. Resourcing indicates the estimation of type and quantities of different resources required to complete individual schedule tasks. In task duration estimation the amount of time needed to perform each task is assessed. Schedule development includes the analysis of task sequence, resource requirements, durations, and schedule constraints to formulate the project schedule. Finally, the schedule control considers controlling needed changes to the project schedule. (PMI, 2004 and Hendrickson, 2008)

Winch and Kelsey (2005) have defined the sequence of planning activities. In projects (EPC), the sequence of action is defined generally:

Engineer ⇨ Procure ⇨ Construct

However, the actual planning process has to be performed in reverse:

Construct ⇨ Procure ⇨ Engineer

From a planning perspective, procurement and design are merely inputs into the construction or execution phase on the site. Planning is started with the identification of the overall site construction phase followed by identification of overall procurement sequence and finally identification of design information delivery. That sequence is usually applied to scheduling as well and it is considered when sequencing tasks in the schedule development phase.

2.3 History of Project Scheduling

In this section the history of project scheduling will be presented briefly from ancient times to the present day. Well-known and important scheduling methods developed over the years will be described in more detail alongside the history. Other currently-used systems and methodologies will be presented at the end of the chapter. Significant events in the history of scheduling are indicated in the Figure 5.

The literature concentrating on the history of scheduling is scarce. All the books throughout history describing different methods could not be reviewed due to the limited time and scope of the study. The insight should be treated with caution because of the few source books used in this section.

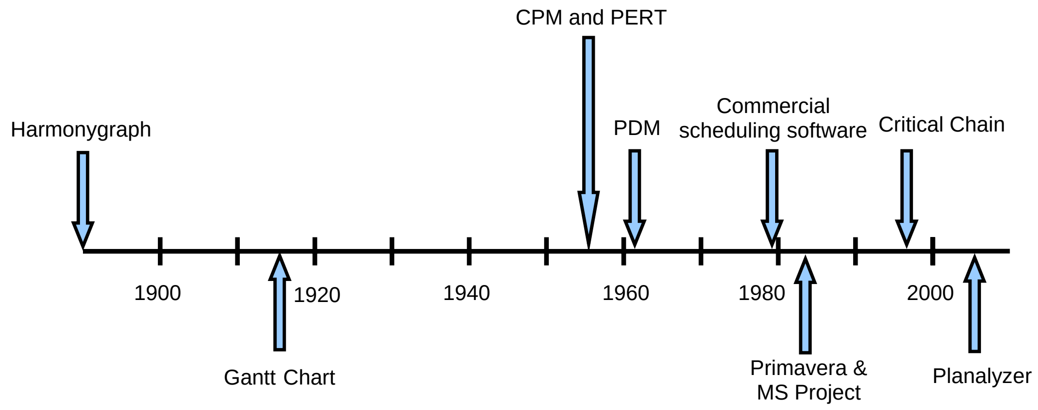


Figure 5 History of scheduling

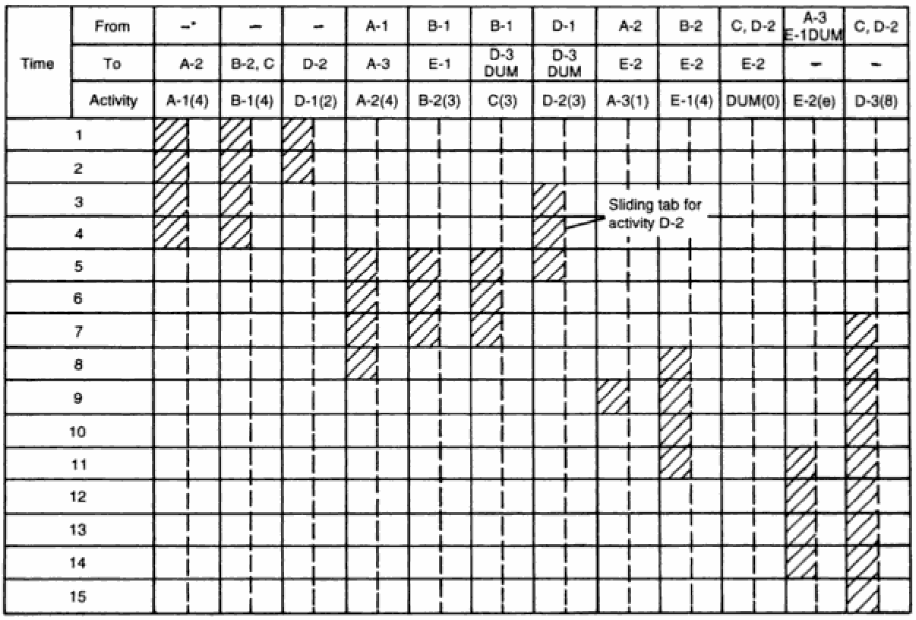
2.3.1 From Ancient Times to the 19th Century

Even in the ancient times projects were often constructed with great consciousness of the importance of time. Consequently, the concept of project scheduling is not new.

The pyramids, the Great Wall of China and aqueducts of the Romans are over 2000 years old. None of these constructions and assignments could have been completed without planning and some kind of schedules. Archeologists have been studying these endeavors, but there is little evidence of formal processes till the 20th century.

Between the 15th and 17th centuries concepts of engineering science were emerging and these were applied to management of large projects. In the 18th century the engineering complexity of projects increased and separation of design and construction works was the birth of consulting. (Morris, 1994)

One of the earliest known scheduling tools is Karol Adamiecki's Harmonygraph, presented in Figure 6. The Theory of Work Harmonization was developed in Poland in 1896. The Harmonygraph includes features which make it a distinct predecessor to the widely-used CPM and PERT methods developed 60 years later. The Harmonygraph has a date scale on the vertical axis and a list of tasks on the horizontal axis on the top. The sequence and duration of tasks are shown by a sliding tab like a bar in a bar chart. The Harmonygraph also indicates predecessors and successors of each task. Adamiecki's chart never became popular in project scheduling because of the unpopular language. The chart was not published until 1931. (Cornish, 2008 and Morris, 1994)



*The first column or strip represents activity A-1, where (4) indicates the estimated time to perform this activity. The dash in the 'From' row indicates that activity A-1 has no predecessor activities, and the A-2 in the 'To' row indicates that it is a successor to A-1.

Figure 6 Adamiecki's Harmonygraph (Morris, 1994)

2.3.2 Early 20th Century - Gantt Charts

American engineer Henry Gantt developed a bar chart (Gantt chart) in 1917 as a visual production scheduling tool. It became a popular method and is in wide use today in an essentially unaltered form. (Cornish, 2008) The Gantt chart indicates tasks and time in a graphical format allowing the allocation of tasks in time horizon, but not determining interdependencies between tasks. Gantt charts were first used on large construction projects and they proved their efficiency in remarkable projects like the Hoover Dam, started in 1931 (Wikipedia, 2008).

Another type of chart which came into regular use in the 1950s was a milestone chart. It was used along with Gantt charts. Major projects were subdivided into components with target dates set for completing tasks required to achieve each milestone. Milestone charts are also widely used today, especially for management reporting. A major benefit is the easy communication of large amounts of information. (Cornish, 2008)

2.3.2.1 Description of Gantt Charts

Gantt charts are the simplest and most widely-used scheduling technique today in all fields because of its easily understandable format. Almost any user can read the schedule without prior training or knowledge. The Gantt chart can be used as an only scheduling tool when preparing a schedule or it can be used as a graphic presentation format for schedules established by other scheduling techniques. (Willis, 1986)

The Gantt chart is a rectangular diagram consisting of a horizontal axis for time units and a vertical axis for tasks or work packages. In the diagram, tasks are listed on the left-hand side and the time scale along the bottom. Each bar shows the start and end and, thus, the duration of a task. A simple Gantt chart is presented in Figure 7. (Nicholas, 2004)

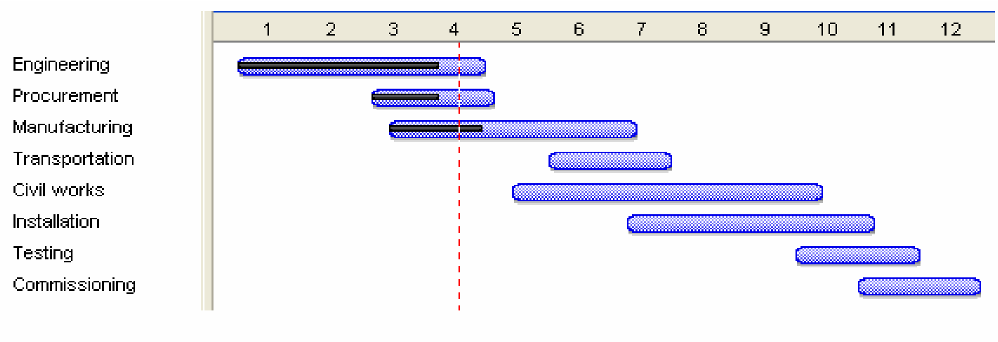


Figure 7 Gantt chart

Gantt charts suffer from a few drawbacks. They do not showing any kind of precedence relationships (interdependencies of tasks) and do not contain information on resource levels for tasks. They only indicate when the task starts and when it finishes. However, there is an enhanced version of the original Gantt chart, referred to as a linked Gantt chart that includes precedence dependencies. The chart can also be used for monitoring progress of the project, as shown in Figure 7. Black bars inside the blue task bars indicate the progress. Bars without any black bar indicate tasks which have not yet been started. A vertical red line (dashed) indicates the present day. (Rolstadås, 2004)

2.3.3 Late 20th Century - Critical Path and PERT Methods

The Critical Path Method (CPM) and Program Evaluation and Review Technique (PERT) were developed simultaneously in the 1950s. They are remarkably similar to each other, both using an arrow diagramming method, but were developed for fundamentally different business fields. CPM was aimed for the construction and maintenance industry where technologies and processes were largely known and estimations of task durations could be done with some accuracy. In contrast to CPM, PERT was focused on military research and development (R&D) where time pressures were high and costs a secondary issue. In an R&D environment, activity durations were difficult to estimate, thus, PERT emphasized probability. (Morris, 1994)

2.3.3.1 Development of the Critical Path Method

The origin of the CPM may be traced back to 1956. E.I. Du Pont de Nemours (Du Pont) in the USA was one of the very first owners of computers installed in a commercial business and they were looking for useful tasks to do with their UNIVAC I computer. One possible use of the computer was to determine the best trade-off between time and cost and Du Pont's management felt that estimating of scheduling seemed like a practical task for optimization. (Morris, 1994)

By 1957, Morgan Walker assisted by James Kelley had developed a model for the time-cost problem. They could demonstrate that focusing effort on the right tasks could reduce time without significantly increasing cost instead of recovering lost time with a bulk of labor. The challenge was to determine the right tasks. The activity-on-arrow diagram was used to explain the calculations of the method. (Cornish, 2008)

Development continued through 1958 and in 1959 CPM was presented publicly. Regardless of many innovations, CPM nearly died as a concept until 1959. However, Kelley together with his associates formed their own consulting firm and commercialized CPM. They focused on schedule (rather than cost) and organized training of the method. Although CPM was expensive – solving scheduling problems could cost the price of a small car – it become very popular and moved to the forefront of scheduling methods (overtaking PERT). (Cornish, 2008)

2.3.3.2 Development of PERT and Associated Systems

The PERT method was developed by the US Navy Special Projects Office (SPO). The SPO for a missile program (Polaris) was established in late 1955. During 1956, the SPO investigated the systems used by other companies and organizations for large-scale projects, but could not find significant added value. A small team consisting of SPO members and outside consultants was established to progress the development work. The team developed a list of features for the system, including careful task time estimates, probability distributions, and precise knowledge of the sequencing of tasks. (Morris, 1994)

Core parts of the method included the collection of task estimates from bench engineers and the calculation to identify the longest sequence of events in the project, also called the critical path. In mid-1957 the basic concepts of PERT procedures had been published, and the method was being run on computers. In fact, the PERT method was not widely used within the Polaris program because of lack of trust in the method in SPO. Interestingly the method was effectively publicized because the first Polaris missile was launched in 1960, and by 1964 the PERT bibliography comprised almost 1000 books and articles. (Morris, 1994)

2.3.3.3 Activity-on-Arrow Method

The linked Gantt chart presented earlier can show precedence relationships between tasks, but is not suitable if the project schedule is complex. Network techniques can handle complex dependencies better. The graphical presentation of schedule can be done in a Gantt chart format. Two types of network representations exist: activity-on-arrow (AOA), and activity-on-node (AON). Activity-on-arrow will be discussed first and the activity-on-node method will be presented later on because both, CPM and PERT, activity-on-arrow methods were eventually replaced by precedence diagramming methods (activity-on-node) in the 1970s.

The AOA technique is also called the Arrow Diagramming Method (ADM). AOA is a method to formulate a schedule network diagram. In order to construct a network, a list of tasks, precedence relationships, and estimations of task durations are needed. Tasks (activities) are presented as arrows which are connected at nodes which present events (circles). The arrows also define the precedence relationships. In Figure 8 in the next section a network diagram constructed using the AOA method is shown. Because tasks are linked through nodes, finish-to-start connections are only used. However, it is possible to define all other task relationships if dummy activities are introduced. Dummy activities have no work content, and are usually drawn with dashed lines. (PMI, 2004 and Turner, 1999)

2.3.3.4 Critical Path Method

CPM is a network technique for scheduling a set of project tasks. The critical path is the sequence of project network tasks with the longest overall duration which determines the shortest completion time of a project. When using CPM, the earliest and latest start and finish dates are calculated for all schedule tasks. These are determined by performing a forward and a backward pass analysis through the network paths. This process indicates which tasks are critical, in other words, on the longest path. Schedule flexibility is calculated by the difference between early and late dates, and is termed total float. It shows the tasks which can be delayed without making the project longer. Critical paths have a zero total float, and tasks on a critical path are called critical tasks. Any delay on the critical path directly impacts the project completion date. The critical path can be affected by adjusting activity durations, precedence relationships, leads, and lags. The concept of the critical path is seen as useful because it draws attention to the tasks that need the closest monitoring. (PMI, 2004)

Figure 8 shows the results of AOA calculations for a network. For each event, the earliest and latest possible times the events can occur are determined.

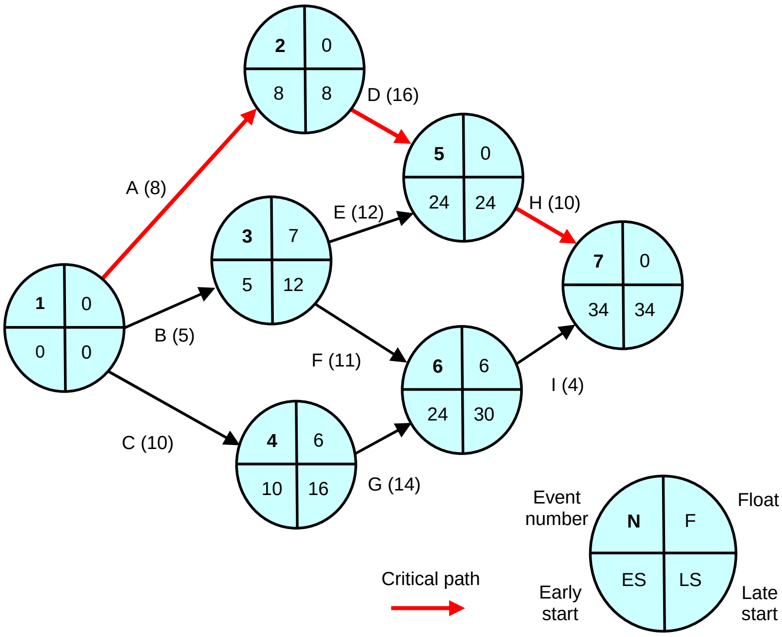


Figure 8 CPM calculations for an AOA network

Float is also indicated in Figure 8. For example, task G is limited by the early time of event 4 (10), and the late time of event 6 (30). Thus, the time allowed for task G is 30 - 10 = 20 days. The duration of G is only 14 days, which means a float of 20 - 14 = 6 days. The start time of task G may be delayed by up to 6 days without affecting the completion of the project. Tasks with no float are denoted critical tasks and a chain of critical tasks from start to completion in the network is called the critical path. In Figure 8 the critical path is A-D-H.

2.3.3.5 PERT

The PERT method can be considered an extension of CPM by incorporating variability in task duration estimates. Uncertainty of task durations is taken into account by using three time estimates for each activity. (Wei, 2002) In the PERT the most commonly applied distribution is a beta-distribution, where O and P are optimistic and pessimistic estimates and M the most likely duration. With different O, P, and M values almost any skewed distribution can be prepared and in most cases the distribution is skewed to a pessimistic direction, indicating that a delay is more likely than an early completion. All task durations are considered stochastically independent, which means that a delay in one task will not lead to a similar delay of another activity task. (Rolstadås, 2004)

In the PERT method the expected durations are calculated for all tasks and then the network is calculated by the AOA method as in CPM using these expected values as task durations.

When using beta-distribution, the expected task duration E(t) and variance Var(t) is calculated:

$$\mathrm{E(t)} = \frac{O + 4M + P}{6} \qquad \text{and} \qquad \mathrm{Var(t)} = \frac{(P - O)^2}{36}$$

The variance indicates the uncertainty of the duration. A larger variance indicates greater uncertainty in the estimates. (Rolstadås, 2004)

2.3.3.6 European Developments

The development of scheduling methods and systems did not take place solely in the USA. Europeans also developed different systems for scheduling, but none of them remained as a dominant method. At the end of the 1960s the PERT and CPM methods had developed as standard dominant systems.

The British chemical company Imperial Chemical Industries (ICI) developed a technique which was a predecessor of CPM as early as in 1955. ICI's "controlled sequence duration" was used for plant maintenance scheduling. The method was never widely publicized and little information has been found concerning the system. (Morris, 1994)

The Central Electricity Generating Board (CEGB) in the UK was developing their version of critical path and in 1957 CEGB came up with the technique of “longest irreducible sequence of events” (later renamed “major sequence”) in the maintenance of generating plants. With this scheduling technique CEGB was able to reduce the shutdown time of plants by over 40%. This method was not publicized and never became a popular system. (Morris, 1994)

A system which was like PERT called *Setevoe planirovanie i upravlenie* (network planning and management) was developed in the Soviet Union (Russia). It was published in 1969, but was never popular in Western countries. The Metra Potential Method (MPM) was developed in 1958 in France. MPM introduced the idea of lags in the scheduling algorithms. A method called RPS (*Regeltechnischen Planning und Steuerung*) was developed in Germany in 1960 which also uses lags in the AON system to calculate critical paths. Although these systems were developed in Europe, John Fondahl’s precedence diagramming method, published in 1961 in the USA, has many similarities to these systems. (Morris, 1994)

2.3.3.7 Development of Precedence Diagramming Method

In 1961 John Fondahl at Stanford University published a report “A Non-computer Approach to Critical Path Methods for the Construction Industry.” This paper described the precedence diagramming method (PDM) system of scheduling. At that time large construction companies were just beginning to use computers for scheduling, but Fondahl wanted to introduce a method to still do scheduling without computers which were large and very expensive. His publication sold thousands of copies and was translated into more than 20 languages. The PDM system used a “circle and connecting line” diagram. Both CPM and PERT used the AOA notation. One of the features of Fondahl’s methodology was lags and precedence matrices. (Cornish, 2008)

In 1964, IBM published a project control system (PCS). The extended node system of scheduling, called precedence diagramming, presented complex overlaps, lags and leads between tasks with great simplicity. Fondahl’s work continued at Stanford and in 1964 publication of a second report caused a selection of the terminology to the methodology. Although tempted to use AON, he selected the term “precedence diagramming” used by IBM. (Morris, 1994)

The techniques of the non-computer approach that Fondahl developed were easily adaptable to computers, expediting the switch from hand calculations to computer-based methods.

The transition of Fondahl’s non-computer approach to a computer-based system appears to have been started by the Texan construction company, H.B. Zachry. Zachry began scheduling with the CPM of construction projects in 1959. After the actual use of the CPM technique was recognized benefits and drawbacks of the method and research were directed toward exploration of new methods and applications of network scheduling. In 1964, based on the work of Fondahl, Zachry and IBM published development of a system for project scheduling as a joint venture. (Morris, 1994)

Eventually Fondahl’s PDM became the dominant mainframe-computer scheduling methodology. This development continued through mini-, micro- and personal computer applications and in the 21st century PDM is virtually the only commercially available computer-based method for scheduling. PERT has almost died out completely and AOA (arrow diagramming method) is rarely used and only found in presentations where the calculations are performed manually. (Cornish, 2008)

2.3.3.8 Activity-on-Node Method

AON is a method of establishing a project schedule network diagram. In the AON technique, boxes or rectangles, referred to as nodes are used to present tasks. Tasks are connected to each other with arrows that show the dependencies. Events are not indicated in AON networks. This technique is also called PMD, and is the method used by most project management software tools. In AON, dependencies or precedence relationships can be indicated with four types of connections: finish-to-start, finish-to-finish, start-to-start, or start-to-finish. (PMI, 2004)

Critical path analysis of an AON network is similar to an AOA network calculation, but events are omitted. Figure 9 shows an AON network for the same network as in Figure 8, calculated by AOA. In AON, early start and finish dates are calculated by a forward pass. After that late start and finish dates and float are calculated in a backward pass. Critical path is identified as a path with zero float.

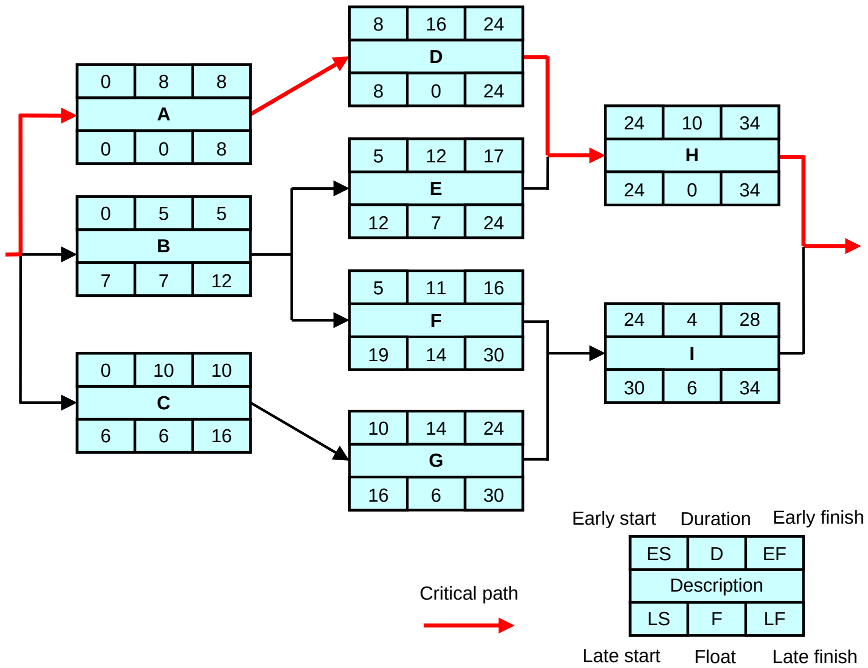


Figure 9 CPM calculations for an AON network

In traditional networks the precedence relationships were indicated only with finish-to-start type connections, where the finishing of one task is related to the start of the next task. However, it is possible to define all other relationships, as indicated in Figure 10.

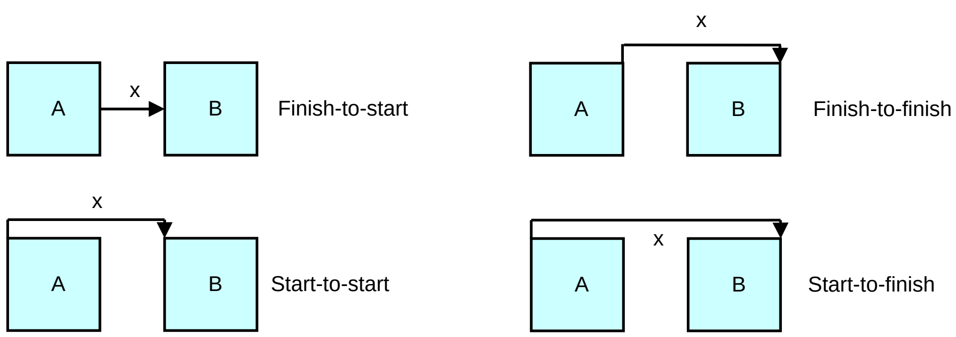


Figure 10 Precedence relationships

Finish-to-start relationships are most commonly used, while start-to-start is used occasionally, finish-to-finish rarely, and start-to-finish almost never used.

2.3.4 Mid-1960s Onwards - Growing Construction Industry

Until the mid-1960s the evolution of modern project management was virtually dominated by the US defense and aerospace sector in their major projects (Manhattan atomic bomb, Polaris missile and Apollo lunar), since almost all the basic techniques and methods were pioneered there. After that the number of projects in the construction industry using modern project management methods increased strongly. To overcome technical and organizational challenges, new insights and methods were developed for project management. In addition to construction industry developments, interest towards project management was also growing in business schools, academia and general industry. That development broadened and expanded project management to other fields and increased research efforts. (Morris, 1994)

During the 1960s and 1970s network scheduling, cost control and other project management tools had been implemented throughout the USA and Europe. Hundreds of articles were published only about network scheduling. Heuristic methods were developed to deal with resource allocation, which was largely a theoretical field at the end of the 1960s. The complexity of resourcing required unrealistic amounts of mainframe computer time, which was very expensive. (Morris, 1994)

2.3.5 Late 1970s to the Present Day - Computer Systems

Through the early 1980s project schedules were usually prepared by first drawing them manually to sort out problems. Then the corrected and checked schedules were loaded in the mainframe or mini-computer and calculated. On mainframe days it was considered that inexperience of scheduling could cause costly and time-consuming problems. To prevent this, schedulers were trained through a process of practical training and mentoring. That led to the evolution of skilled project schedulers who possessed the know-how of scheduling. Standardization of scheduling processes and collection and use of schedule data was developed to be more effective in organizations with departments for scheduling. (Cornish, 2008)

During the late 1970s, the arrival of more powerful project scheduling systems running on micro-computers caused the major change in scheduling. Soon after computers software tools for scheduling also appeared. Planning Services in the UK launched the first commercial scheduling software for Apple computers in 1979. (Cornish, 2008)

The first IBM personal computer (PC) was introduced in 1981 and a year later, a scheduling software was launched for PC systems. Primavera and Microsoft have been competing since the early days of PC-based scheduling software tools. Primavera was founded in 1983 and it was focusing on the then mainstream Disk Operating System (DOS). Microsoft was founded in 1975 and the first version of Microsoft Project was released for DOS in 1984 by a company working for Microsoft. That first version introduced the concept of dependency lines between tasks in the Gantt chart. The first Windows-based version was released in 1990. (Wikipedia, 2008)

In the latter half of the 1980s the number of relatively cheap and easy-to-use PC-based scheduling tools increased greatly. The low end tools made scheduling systems available to many users and allowed everyone to do cheap computer-based scheduling. This had two significant impacts: by the early 1990s no one was preparing schedules manually any more, and the number of non-professional users formulating schedules on a part-time grew substantially. Interestingly, attention has currently refocused on the role of professional schedulers because of growing interest in enterprise-level systems. A number of available Internet-based scheduling tools and niche systems have found market potential. Different kinds of risk analysis, simulation tools and add-on packages for dominant systems such as Microsoft Project and Primavera are increasing. (Cornish, 2008) Planalyzer is one of that kind of software tools and it will be presented later on.

2.3.6 Other Approaches to Project Scheduling

The most widely-known scheduling methods were presented in the previous sections and here some more recent techniques for scheduling will be introduced. The literature on the project scheduling methods is extensive and rich, but here some of the methods which seemed to appear often in the reviewed literature will be discussed. The difference between methods in the literature is whether the uncertainty or resource constraints are taken into account.

2.3.6.1 Resourcing

In the previous sections, resource constraints have not been taken into account. However, they apply in practice in many ways when determining the duration of tasks, as a trade-off between time and cost, and as limited resources during scheduling.

Resource constraints affect in early phases of project planning when the project is being scoped and estimations of work volume calculated, as an amount of person-hours for a task or work package. Time and cost trade-off in project scheduling is an optimization problem and operations researchers have found a wide variety of applications for that purpose. These are rarely used in practice because the problem is complex. If the project resources are limited, the problem is referred to as scheduling under resource constraints. The project duration and resource level are the variables that are considered. Trying to fix both creates a very complex problem with no solution. Usually, the approach is to first prepare the schedule without resource considerations. Then the schedule is adjusted with resource limitations and either the resource level or the project duration is kept fixed while the other is kept variable. Resource-constrained scheduling is challenging and it is a combinatorial problem where checking all possible alternatives is impossible, even with the most powerful computers. However, a number of heuristic algorithms to simulate that problem have been developed. (Rolstadås, 2004)

According to Herroelen (2005) much research has been done for the development of project scheduling under various types of resource constraints. Little importance is given to the issue project scheduling in the popular project management literature and textbooks, some of them without even recognizing the difference between resource leveling and resource-constrained scheduling. Resource leveling means leveling resource use over the project duration, while resource-constrained scheduling means minimizing the project duration subject to the precedence and resource constraints.

Wei (2002) has presented methods used traditionally to bypass the resource-constrained project scheduling problem. Visual inspections, graphical and heuristic methods are introduced. Visual and graphical methods are applicable for small and non-complicated projects requiring few resources while the heuristic method is suitable for large and complex projects to seek near-optimal schedule. Some of the existing project scheduling software tools provide resource-leveling capability to resolve resource conflict.

2.3.6.2 Critical Chain Project Management

Critical chain project management (CCPM) is a relatively new entry to the project management practices. It was introduced in 1997 by Eliyahu Goldratt in his book, *Critical Chain*, and it is based on methods derived from his Theory of Constraints. The critical chain method has been widely discussed in project management literature and journals. The reason for its development was the problems in existing methods and approaches, like CPM not taking into account finite resources and task duration fluctuations. CCPM allows project management to shift from a time-oriented (critical path) to a resource-constrained (critical chain) view. (Steyn, 2000 and Rand, 2000)

The critical chain is the longest path through the project, where resource constraints are considered. Usually, the critical chain is not the same as the critical path. In CCPM, it is claimed that the main reason for constant overruns of projects is caused by the safety time included within each task estimate. CCPM tries to take human behavior during project planning into account. One assumption is that the people responsible for project task duration estimates are aware of the existing uncertainty of projects and add safety times to estimates. This can be seen from Figure 11 where PERT and CPM task estimates include safety times and make the total project duration longer. (Rand, 2000)

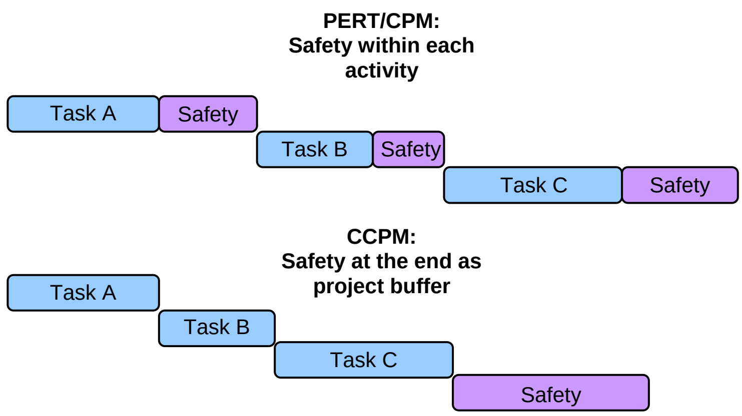


Figure 11 PERT/CPM comparison with CCPM

When tasks which include safety times are linked together, it is thought that the probability in completing on time is high. Task estimates including safety times are known by employees and starts are delayed because there is safety in tasks. This is also called procrastination or student syndrome, which means leaving everything to the last possible moment before the deadline. On the other hand, if tasks are started in time, they are not performed at full effect because of the feeling that there is time till the deadline. This is known as Parkinson's Law (work expands to fill the time allowed). (Rand, 2000)

In traditional project management tasks completed early are a problem because the following tasks are not ready to start immediately after the previous task actually finishes. Any delay in critical tasks delays the entire project, while early completion does not affecting finishing the project ahead of schedule. (Steyn, 2000) Another assumption in CCPM is that completed tasks are not reported to be ready early because workers believe that in the future they can feel pressure to be assumed to finish early also. (Rand, 2000) Workers are not willing to complete their work ahead of schedule because there are no incentives for that. (Steyn, 2000)

In CCPM duration estimates are reduced (50%), but then a project buffer is added at the end of the project, as can be seen in Figure 11. Safety times should be at the project level, not at individual task level. (Rand, 2000) This project buffer is going to protect the project's due date from variability in the critical chain. (Herroelen et al., 2002)

Project schedules can have many parallel non-critical paths, which merge in the critical chain at different times. Delays in any of these paths can delay the critical chain. At the end of the non-critical feeding chains feeding buffers are added to protect the critical chain from disruptions in the tasks feeding it and to allow critical chain tasks to start early in case of early completion, as presented in Figure 12. Traditional methods are using float to manage feeding chains, but float is not well suited for that purpose because it is only the result of network logic calculations. (Rolstadås, 2004 and Herroelen et al., 2002) Resource buffers are used as an advance warning, and they are located whenever a resource has to execute a task in the critical chain, and the previous critical chain task is performed by a different resource. (Herroelen et al., 2002)

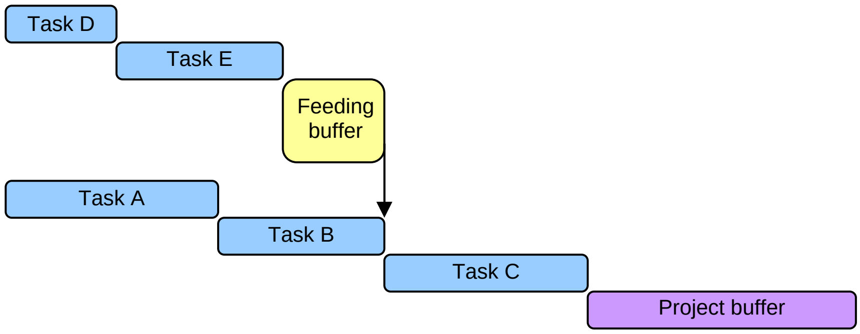


Figure 12 Feeding and project buffers in CCPM

Multitasking is to be avoided in the critical chain method, so that all workers should work on only one project task at a time (Rolstadås, 2004). Tasks are scheduled at the latest start times based on traditional critical path calculations to minimize work-in-progress. (Herroelen and Leus, 2001)

There are two schedules during project execution: critical chain, and baseline, which are fixed. A project is executed by using an un-buffered schedule which is early start-based. Buffer management provides a proactive warning mechanism and control system for CCPM. The consumption of buffers is followed up as tasks are completed and from that can the project progress can be estimated. As long as a predetermined portion of the buffer remains, a project is assumed to go on schedule.

The basic concepts of CCPM are summarized below:

- 50% probability task duration estimates
- No task due dates
- No project milestones
- No multitasking
- Minimization of makespan and work in progress
- Identification of the critical chain
- Aggregation of uncertainty allowances into buffers
- Fixed baseline schedule and critical chain schedule during project execution
- Determination of an early start-based un-buffered projected schedule and reporting of early completions
- Use of buffers as a proactive warning mechanism during project execution

Until recently, commercial software packages were generating only deterministic baseline schedules without any consideration about uncertainty. CCPM has brought specific software tools and add-in packages developed for the critical chain scheduling to the market. (Rolstadås, 2004 and Herroelen et al., 2002)

Critical views of CCPM claim that the probability theory of the method cannot be applied for non-routine projects because of lack of statistical history data. (Herroelen and Leus, 2001) The as-late-as-possible approach is not efficient for managing projects in many cases (Zwikael et al., 2006). The 50% rule for buffer sizing can cause serious overestimation of the required project buffer size and feeding buffers do not work well during project execution as a proactive protection mechanism (Herroelen and Leus, 2001).

2.3.6.3 Project Scheduling Under Risk and Uncertainty

Currently, most project scheduling concentrates on the development of a baseline schedule assuming complete information and a deterministic environment. Preparation of a precedence- and resource-feasible baseline schedule that optimizes the project duration before the start of the project is a common practice in project scheduling. Generally this is performed with deterministic values without any consideration of variability. In reality, projects are subject to varying risks and uncertainty which are not included in the developed schedules. (Herroelen and Leus, 2004) The methodologies for stochastic project scheduling basically view the project scheduling problem as a multi-stage decision process. The literature of project scheduling under risk and uncertainty is rather scarce. (Herroelen and Leus, 2005)

Dawson and Dawson (1998) state that the deterministic nature of the current standard scheduling techniques is not suited to projects with significant uncertainty. Methods for analyzing projects with uncertainty and risk have been available for years, but the knowledge and use of techniques is low.

Uncertainties during project execution may stem from a various possible sources, like task durations can take more or less time than estimated, resources can become unavailable, materials can arrive late, or additional work is needed and weather conditions can change. Herroelen and Leus (2005) have described five approaches to deal with uncertainty in a scheduling environment where the evolution structure of the precedence network is deterministic: reactive scheduling, stochastic scheduling, scheduling under fuzziness, proactive (robust) scheduling, and sensitivity analysis. Unfortunately, these methods can not be introduced in more detail due to scope limitations of this study.

2.3.6.4 Stochastic Simulation

The traditional PERT method ignores the stochastic nature of task durations, reducing the stochastic model to a deterministic model when using duration means in calculations. This analytical simplicity of PERT and CPM is usually replaced by Monte Carlo simulations. The most common stochastic simulation used in project scheduling is Monte Carlo simulation. In the simulation the same input values as in the PERT method can be used. Simulation is generated by randomly pulling a sample value for each input variable from its defined statistical distribution. Input sample values are then used to calculate the network as in usual CPM. The procedure is repeated many times (e.g., 1000 times) until the probability distributions are sufficiently well-represented to achieve the desired level of accuracy. With Monte Carlo simulation, the probability of a task being critical can be estimated while CPM only indicates whether a task is critical or not. If a project schedule needs to consider uncertainty, a Monte Carlo simulation is a useful option and many commercial software tools are available for that purpose. One disadvantage of Monte Carlo simulation results from the additional information needed of task durations. (Rolstadås, 2004 and Hendrickson, 2008)

2.4 Models and Formats for Different Managerial Needs

Project schedules can be presented and communicated in many ways, including simple activity lists, bar charts with dates, or network logic diagrams. Project schedules can take different forms and terms used in practice for different schedules vary substantially. (PMI, 2007)

Nicholas (2004) states that when projects become larger, it is difficult to present all tasks and information on one chart. Schedules can be divided into smaller entities, also called hierarchy of charts. Clough et al. (2000) argue also that schedules must be established on a hierarchical basis, and a schedule at a particular level of detail must be expanded to more detail when the execution of the work comes closer.

Traceability between different schedule hierarchy levels is important to maintain consistency throughout the scheduling process. Winch and Kelsey (2005) have described that a high level planning has to incorporate many lower level plans and plans of subcontractors. Lower-level plans often confirm the robustness of the higher-level plans.

A milestone schedule is a strategic plan above all other schedules, which defines intermediate products to be achieved. It specifies the logical sequence of states the project must pass through, indicating what is to be achieved in each state, but not how it is to be achieved. The entire project scope is defined in this scheduling level. (Turner, 1999)

Below the milestone schedules is usually the master schedule, which outlines the main work packages and represents the major milestones. A master schedule is a type of project schedule which indicates the major project tasks without too much detail. Usually, it is used by the top and project management for reviewing and planning the entire project. It is prepared during the project development phase and after that it is periodically updated during project implementation. The project manager with the project team formulate the master schedule in a top-down fashion. (Nicholas, 2004)

Next in the hierarchy are schedules at an intermediate level, where master-level tasks are presented in more detail, with subtasks. Usually, this level of schedule allows project and line managers to do resource planning. (Nicholas, 2004)

At the bottom level, the schedule tasks are derived from tasks of intermediate-level schedules. These schedules are utilized by site personnel, supervisors, and technical specialists to plan and control activities on a daily or weekly basis. Task schedules are more detailed and contain activities at the work package level. Lower-level managers and supervisors can focus on detailed tasks of their own discipline without being interfered with by other areas they are not interacting with. Task schedules are prepared by line managers and including higher-level milestones and tasks from master schedule broken down into detailed ones. The master schedule is upgraded with necessary details gained from task schedules. (Nicholas, 2004)

Winch and Kelsey (2005) has presented the hierarchy of construction project planning in Figure 13. Italicized boxes in the figure represent contractually binding documents. The process starts from the client's (owner's) strategic programme and moves on according to arrows. The contractually-binding agreement between the client and contractor is the master programme. The contractor prepares the target construction programme which guides the procurement programme and the work contractor's (subcontractor) programme. Within the target programme, subcontractors are given time windows where they are expected to perform their works. Within works contractors' programmes, subcontractors schedule task execution at the level of the WBS. Often, construction managers do not reveal the master programme to the subcontractors, but provide a target construction programme which is tighter than the master programme, to get a buffer if the subcontractor's programme slips.

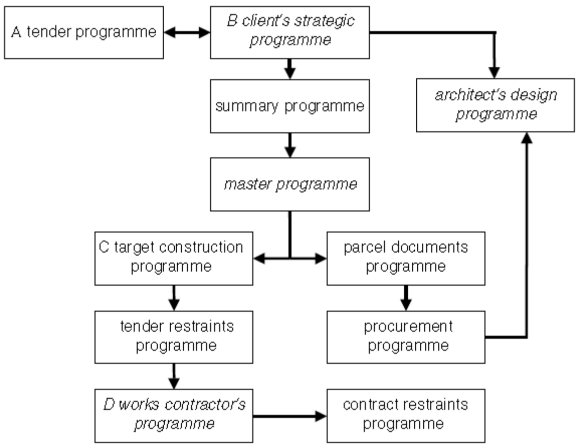


Figure 13 Hierarchy of construction project planning (Winch and Kelsey, 2005)

A hierarchy for scheduling can be derived from the construction project planning hierarchy presented in Figure 13. Figure 14 presents a hierarchy which contains five levels. In small-scale projects, only two levels can be used, while large and complex projects can have even more than five levels.

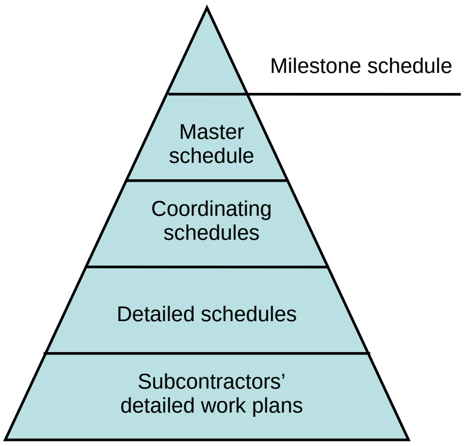


Figure 14 Schedule hierarchy

Alsakini et al. (2004) have also discussed that the prime contractor of the project sets the general timing for the overall project. Different subcontractors provide portions of the plan relevant to their work and develop details concerning their operations. Separate work schedules are linked into a summary schedule, which is extended by dividing it into sub-networks. These schedules with more detail can be planned and controlled by the employees directly concerned. This procedure will get the prime contractor and subcontractors to solve problems in the early stages.

The appropriate level of task detail in schedules is discussed in PMI's The Practice Standard for Scheduling (2007). Too little detail hampers project control because necessary information is not readily available. Too much detail makes a schedule too large and consequently difficult to interpret and laborious to manage. That level of detail is suitable which a person using the schedule knows exactly what needs to be done without having to rely on other information.

Another issue to consider is the appropriate cycle for updating the schedule. That depends on the type of schedule. The rate of change in the project affects to the choice of schedule and cycle time. As a simple rule, the period between updates needs to be long enough so that the project team has had time to act on the new information prior to the next updates. (PMI, 2007) The timing issue is described more detail in the next section.

2.4.1 Timing of Planning

The timing dilemma of planning is discussed by Laufer and Tucker (1988). If the time interval between planning and implementation is long, the uncertainty concerning planned activity is higher. The higher the uncertainty in a project, the more difficult it is to plan. The earlier the project planner is involved with all relevant functional areas, the greater influence he has on its execution.

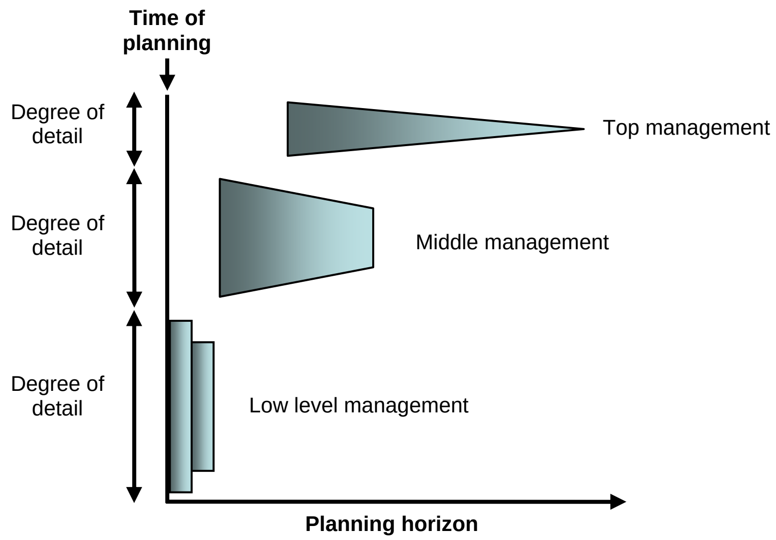


Figure 15 Analogy between planning horizon, degree of detail, and management level

Laufer and Tucker (1988) have proposed solutions for the above-mentioned timing problems. They have connected the planning horizon, degree of detail, and management level in the Figure 15. The degree of detail should vary in the planning horizon, hence more detailed closer to implementation. Top managers maintain long-term horizon in planning while low-level management is interested in the coming few months. The degree of detail matches the management level as well as the hierarchy of schedules. Detail level varies across the given planning horizon from more to less detailed. For lower levels, detailed short-term plans of the immediate future are prepared more often, while for top management long-term plans with a low level of detail are established less frequently.

Alsakini et al. (2004) and Laufer et al. (1992) have suggested a proactive schedule management system in their study. It allocates less detailed scheduling to the home office and more detailed planning and control to the site organizations. This model facilitates dialog between project stakeholders because subcontractors are taken into the scheduling process early. The introduced system consists of a master schedule which is for the entire project. Work schedules are extensions of the master schedule by using a rolling window or look-ahead method. These schedules are established by project and site managers for a time span of two months at one-month intervals (for a 12 month project). The third and most detailed level is of a two-three weeks action plan. That schedule is prepared and updated every one or two weeks and includes tasks from a rolling window presented in detail and indicating what will be executed on site. Corrective actions can be taken into account at the end of each period, when scheduling in detail for the next period. The master schedule is kept as a reference point and not changed, while detailed schedules can be used to bring the project back to track if needed.

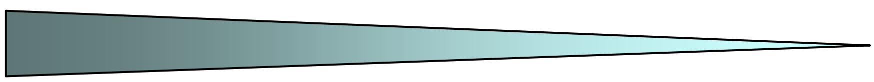
2.4.2 Users and Producers of Schedules

The purpose of planning is correlated with the users of the plans. Users can be divided into the following groups: owner, design engineers, home office, site management and various subcontractors and suppliers (Laufer et al., 1994). The owner and subcontractors can be classified as consumers of plans which are established by the contractor. Table 2 shows various user needs for planning classified by objectives and the relative political power of users. It can be noted that high relative power is associated with a high level of need for forecasting and control, while execution and optimization is the role of weaker parties. (Laufer and Tucker, 1987)

Table 2 Planning objectives affected by user's planning needs and their relative power

Objective	User					
	Owner	Contractor home office			Construction site	
		Top mgmt	Middle mgmt	Planner	Sub-contractors	Work mgmt
Forecasting	Very high	Very high	Very high	Moderate	Moderate	Low
Controlling	Very high	Very high	Very high	Moderate	Very low	Low
Coordination	High	Moderate	Very high	Moderate	Very high	High
Executing	Very low	Very low	Very low	Very low	Very low	Very high
Optimizing	Very low	Very low	Very high	Very high	Very low	Very low

User's Power



(Laufer and Tucker, 1987)

Laufer et al. (1994) have examined the relative planning effort of different participants on different project phases and plan types. In Table 3 the planning effort is indicated by relative time invested in the preparation of each functional plan. For example, number 30 in the upper right corner in the table means that the planning effort invested in engineering and method at during-construction planning is evaluated at 30% of that invested in schedule (100%) effort. Results are relative to each other only within a planning phase. As the results show, the planning is mostly performed at the pre-construction phase. Schedule is the most invested in the preparation of various plans throughout the project's lifecycle.

Table 3 Key participants and relative planning effort (%)

	Planning phase		
Plan	**Pre-bid planning**	**Pre-construction planning**	**During-construction planning**
Engineering and method	PM 41	GS, DE 33	PM, GS, PE, DE, SC 30
Organization and contract	PM, HO 52	PM 43	PM, HO, GS, PE 18
Schedule	PM, HO, SC 82	GS, SC, PM, PE 100	GS, PE, PM, SC, CL 100
Cost and cash flow	PM, HO 100	PM, SC, GS, HO, CL 52	PM, PE, GS, HO 68
Major equipment	PM, HO 34	GS 47	GS, PM, PE 27
Layout and logistics	PM 39	GS, PM 61	GS, PM 33
Work methods	HO 47	GS, PM 55	GS, PM, SC, PE 38
Manpower allocation	- 22	SC, GS 37	GS, PE, PM, SC 43
Materials allocation	- 21	GS, PM, SC 33	GS, PE, SC, PM 25
PM = project manager, SC = subcontractor, GS = general superintendent, CL = client / owner, PE = project engineer, DE = design engineer, HO = home office			
Participants are listed in descending order of their relative degree of involvement.			

(Laufer et al., 1994)

As can be seen in Table 3, various actors are performing planning. The project manager is involved in all scheduling phases, but the effort reduces when a project is proceeding to the implementation phase. That can be explained by Laufer and Tucker's study of the competence and timing dilemma (1988). The project worker specialized for planning has the quality time to perform the work, but often incomplete practical knowledge. The project manager has sufficient practical knowledge and information, but not enough quality time to prepare the plans. As a conclusion, both the planner and the manager possess only a part of the necessary competence and, therefore, both are needed for effective planning. Winch and Kelsey's (2005) study also reveals that better understanding of site and subcontractors' processes are vital knowledge areas for planners.

2.5 Applications - Computer Programs

This section gives an overview of computer-based project management tools, their features and usage. One part of this study will concentrate on one particular Microsoft Project add-on software tool which will be presented later. In addition, the case studies will focus also on the usage of software tools in case companies.

Computer programs have a central role of today's scheduling process. Project management information system (PMIS) can be defined as a tool which supports and facilitates the delivery of projects, especially those which are complex, subject to uncertainty, and under tight competition, time, and budget pressure (Jafaari and Manivong, 1998). PMIS provides a methodology for project planning and scheduling for collecting, organizing, storing, processing, and disseminating data and information (Nicholas, 2004). PMIS are nowadays mainly computer-based systems which can be a part of companywide ERP systems. PMIS usually include features assisting project managers in scheduling, cost control, budget management, resourcing, communication, quality management, and documentation. An effective system enables facile control, analysis, forecasting as well as accurate handling of large amounts of information. (Raymond and Bergeron, 2008 and Nicholas, 2004)

Raymond and Bergeron (2008) have divided PMIS functions into five categories. The planning function is used to prepare the overall project plan, which includes WBS, resourcing, scheduling, Gantt, PERT, and CPM. The monitoring function is used to regularly evaluate the progress which comprises progress reports and curves. The controlling function is used to make specific changes to forecasts, tasks, resources, and the budget. The evaluation function is targeted for project auditing which provides tools for identification of resources, cost, and schedule variances. The reporting function provides an overview of the project.

A model of the PMIS within the project management system has been introduced by Raymond and Bergeron (2008). Figure 16 shows factors which affect PMIS, and which PMIS is affecting. Environmental, organizational and project data are seen as inputs to PMIS which in turn provides information for the project manager and top management. The project manager uses the data received from PMIS to evaluate decisions concerning the project. This process creates a continuous cycle of input and output data to and from the PMIS.

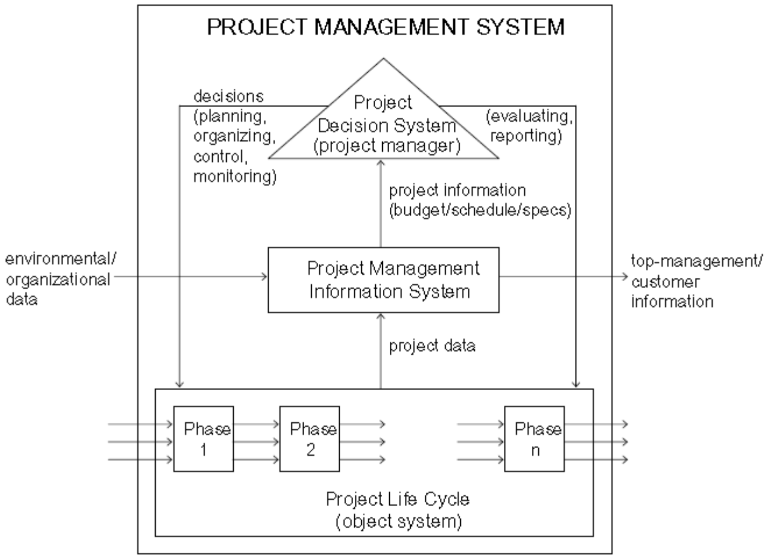


Figure 16 PMIS within the project management system

Currently, the project management software market offers a vast variety of different tools, which can be divided into desktop and Web-based applications. According to Jafaari and Manivong (1998), PMIS can also be grouped into two different types of systems. First are systems developed in-house in a company as proprietary systems which are not generally distributed. Another group is commercially developed and marketed or developed as part of university or institution research projects.

Although the tools have improved in recent years, it should be kept in mind that a system's outputs are only as good as its inputs. Therefore software packages need appropriate and accurate data inputs, periodical updates, and output information distribution to the people who need it. In other words, PMIS needs a well-maintained manual support system. (Nicholas, 2004)

There have been few studies on the actual effects of PMISs, despite the theoretical and practical importance of these systems to the project management. Raymond and Bergeron (2008) indicate that PMISs have been found to have impact on project success because they enhance control as well as meeting targets and specifications. PMIS itself has no direct impact on project success, other than through higher quality of information and contribution to managerial work. Results show that use of PMIS is advantageous to project managers by improving effectiveness and efficiency in terms of better planning, scheduling, monitoring, control, and timelier decision making.

PMIS usage has also been identified to have negative effects on project management. Jafaari and Manivong (1998) have compared drawbacks and limitations of PMISs in theory and Herroelen (2005) in practice as perceived by project managers.

Dawson and Dawson (1998) have listed uncertainties which are difficult (if not impossible) to model with conventional project planning software tools:

- tasks with a wide range of possible completion times
- tasks which may not be needed at all (depending on the outcome of previous tasks)
- tasks which may need to be repeated (if the number of repetitions is unknown)
- tasks which need to be abandoned before the completion

Analysis of schedules with probability distributions for each task is complex, but simulation has been established for that purpose and some software planning tools on the market include that feature.

Dawson and Dawson (1998) also suggest that even without analysis of a schedule, the task probability distribution networks encourage the project planner to consider uncertainties involved and highlight the areas which need more attention. Thus, the planner is in a position to act early to avoid undesirable things from happening.

2.5.1 The Use of Software Tools

Prior to the 1980s, project scheduling was different from current practices. Computer-based scheduling was considered very expensive, required much training and know-how and it was largely centralized. Manual scheduling was used for cost savings, but it was time consuming. On the other hand, the schedulers were trained professionals. The arrival of easy-to-use graphical user interface (GUI) scheduling tools changed the project scheduling field. Scheduling moved from central computers to PCs and scheduling was considered a job anyone could do. Scheduling was not a professional job, which needed training and understanding of scheduling methodology any more. Although the scheduling software tools facilitated the construction of schedules, most schedules were not on that level as before any more. Consequently, the trend changed and the focus was then on computer programs and formulating a schedule to look good rather than analyzing a project and designing the schedule to be an effective management tool. (Cornish, 2008)

White and Fortune's (2002) study of current practice in project management indicated that most respondents (236 responses) used only a small number of methods, tools and techniques with project management, Gantt charts being the most widely used aids. Nearly half of the respondents reported problems with these methods, tools and techniques they were using. In the same study, it was also identified that 28% of respondents did not use any method or methodology (e.g., PRINCE - PRojects IN Controlled Environments) for project management, but over 95% of respondents used at least one project management tool (e.g. CPM, Gantt charts, WBS, PERT). Off-the-shelf software was the most commonly used project management tool (77%).

Use of software tools for project planning has been surveyed by different authors. Pollack-Johnson and Liberatore (1998) have surveyed (240 responses) members of PMI. Results revealed that over 50% of project management professionals use software tools for all their projects. 95% of software users use it for planning, 80% for control, and nearly 70% for general work planning and presentations. Nearly 90% use critical path analysis and over 60% use resource leveling. When considering the packages used, Microsoft Project is used by 71% of respondents, followed by Primavera Project Planner P3 at 31% and Timeline at 12%. According to Raymond and Bergeron's (2008) research of PMIS tools, 38% use more than one software, and Microsoft Project is used by 90%, followed by Work Bench 15% and Primavera 10%.

Bounds (1998) has identified that 80% of respondents (totally 54) used some kind of project planning software. The industrial engineers identified ease of use (59%

ranked it first and 26% ranked it second) and flexibility as the most important attributes of project management tools. Respondents ranked the most important capabilities of tools and one interesting finding shows that the importance attached to resource-constrained project scheduling in published academic papers is in contrast with the results because resource analysis was not highly ranked (12% ranked it first and 14% ranked it second).

From many studies it appears that the two most used project management software packages are Microsoft Project and Primavera Project Planner (Herroelen, 2005). In Table 4, the primary usage of different project management software tools of PMI members specified by industry can be seen. The results of different studies depend on regional practices because MS Project seemed to be more used in Europe while Primavera in the Americas. MS Project is common in most fields while Primavera dominates large and complex industrial projects.

Table 4 Primary usage of project management software packages by industry (%)

	Industry								
PM SOFTWARE PACKAGE	**Construction**	**Pharmaceutical manufacturing**	**Other Manufacturing**	**Resources**	**Computers / Software / Data Processing Services**	**Telecom Services**	**Engineering Services**	**Other Services**	**All Respondents**
Primavera	51,4	25,0	11,5	25,0	6,3	9,8	34,8	27,1	**20,5**
MS Project	24,3	25,0	61,5	50,0	54,2	61,0	34,8	49,2	**48,6**
Timeline	2,7	0,0	7,7	0,0	2,1	0,0	1,5	1,7	**2,9**
Work Bench	0,0	0,0	3,8	0,0	12,5	4,9	0,0	5,1	**4,8**
Project Scheduler	10,8	0,0	3,8	0,0	6,3	12,2	6,1	3,4	**5,2**
Others	10,8	50,0	11,5	25,0	18,8	12,2	22,7	13,6	**18,1**
Respondents (amount)	**37**	**8**	**26**	**4**	**48**	**41**	**66**	**59**	

(Liberatore and Pollack-Johnson, 2003)

3 Evaluation of Schedule Quality

According to Zwikael and Globerson (2004) and Dvir (2003), inappropriate planning results in project failure, whereas high-quality project planning increases the project's chance of success, but does not guarantee it. Implementing the project according to its plan does not automatically ensure a successful outcome. A project manager must ensure that not only is the planning carried out according to the planning process, but also somehow assess that the plan is feasible and reliable. Nevertheless, the importance of project planning is widely recognized: there are no tools developed for measuring the quality of scheduling. Winch and Kelsey (2005) have conducted interviews among project planners which indicated that systematic review of project planning is rare or non-existent.

Zwikael and Globerson (2004) claim that there are no available models for evaluating the quality of planning. Therefore, their research has taken benefit from identifying models that are used in similar environments. They have introduced a model for evaluating the quality of project planning called Project Management Planning Quality (PMPQ). The model is divided into four organizational support areas and nine project knowledge areas similar to PMBOK (PMI, 2004). The model contains 33 items totally, and based on these the quality index is calculated.

In Zwikael and Globerson's PMPQ model time is one of the nine project knowledge areas and it is subdivided into four planning products: project activities, PERT or Gantt chart, activity duration estimates, activity start and end dates. Each of these products was evaluated according to the use intensity with the scale 1 to 5 (1 = product is hardly ever obtained and 5 = product is always obtained) to get the value for quality of time planning.

In PMBOK (PMI, 2004), metrics for quality control have been described. Measuring management quality by monitoring whether planned schedule dates are met is not enough. It must be indicated whether each task must start on time or only finish on time and which tasks will be measured. Establishing a quality checklist is proposed as a structured tool, to verify that the required steps have been performed. Different kind of checklists can be constructed, simple or complex, and formulated as imperatives or queries (Hiltz, 1994).

Ibbs and Kwak (2000) have provided interesting model of project management maturity (PMM) in their study. The developed PMM model is an analysis methodology to assess the maturity of project management processes. The model consists of 148 multiple-choice questions that measure project management maturity, and cover eight knowledge areas (from PMBOK) and six project phases. The questionnaire has 18 questions related to time and scheduling. Ibbs and Kwak suggest that project companies should benchmark their operations using factual, impartial techniques such as those introduced in the PMM assessment questionnaire. This model provides a legitimate reference point for process improvements.

3.1 Software Tools for Schedule Evaluation

During the study one interesting add-on scheduling software tool for MS Project was discovered. It will be inspected more deeply than other tools presented in this study. Planalyzer is a tool for analyzing project schedules and its features induced taking a closer look at it. The tool will be presented in the following sections. The case company schedules will be analyzed with the software in the empirical part.

There are some other commercial software packages which can be used for simulating uncertainties in the schedules. Tools include possibility to perform different analyses based on Monte Carlo simulation and that feature has been incorporated at least in software packages Risk+, Pertmaster (nowadays Primavera Pertmaster) and @Risk. Tools contain features to estimate task durations, resource assignments, precedence relations, and task and resource costs. Simulations use sensitivity analysis, probabilistic branching and conditional “if-then-else” analysis. These software packages are not introduced here in depth due to the limited time and scope of the study.

3.2 Planalyzer Method

Although project management is a well-researched area, the ability to predict project outcomes by using modeling is not well-developed. Currently, the common approach is to use PERT or Monte Carlo simulation, but to provide useful results these approaches need reliable duration distributions for each task. (Fishman and Levitt, 2007)

Ibico Inc. has developed a new method called Planalyzer for calculating project probability based on a quantum mechanical model of project tasks. Planalyzer defines the quality of project schedules quantitatively in terms of probable success by predicting the impact of task slippage on milestones. Project tasks and their duration are modeled as waves, and amplitudes of these waves are expected to be coherent at milestone points. In that model, milestone probability is calculated without any external input and, therefore, it is seen as a fast and easy approach to estimation. In quantum mechanics it is typical to make predictions about outcome based on rather general input information which is seen suitable also for project scheduling. Another feature which makes the method interesting is that it becomes more accurate as the number of tasks increases. (Hoglund, 2006)

3.2.1 Comparison with Conventional Methods

Fishman (2008) indicates that in the conventional schedule analysis (e.g., PERT) tasks are presented by distribution functions, and simulation of these distributions is performed by the Monte Carlo method. Empirically, this method can be called an “expert opinion” and it can provide estimates for project cost and duration. Expert opinions are based on historical data or analogy with similar other projects, thus, the method describes the future of average previous project. Reliable inputs of minimum, maximum, and most likely values are obtained from many different expert opinions, which is time-consuming and need to be done individually for every task.

In classical methods the multiple dependencies between tasks make the calculations difficult, but current computer applications can be used to manage this and several scheduling tools are available to calculate project probabilities based on task probabilities. In real life it is difficult to define task duration probabilities with the required accuracy which is the problem with the classical approach. For large projects consisting of thousands of tasks, moderate dispersion of each task can result in broad probability distributions for the milestone. (Hoglund, 2006)

Planalyzer predicts project duration without any additional inputs to the project schedule. Calculations which are based on quantum mechanics are somewhat new and unfamiliar to project scheduling. One important feature of the quantum model which can be used in schedule calculations is that the project delay is not caused by one task but by collective delay of several tasks. In classical methods that kind of effect can be described by defining individual task distribution functions and task correlations, but this laborious process is often set aside. (Fishman, 2008)

3.2.2 Model

According to Fishman and Levitt (2007), in Planalyzer each task is modeled by a wave which is propagating towards a milestone. Each task can include one or more wave periods depending on the duration of the task. The behavior of task waves is presented in Figure 17 where the wavelength decreases when the task contracts, and increases when the task expands.

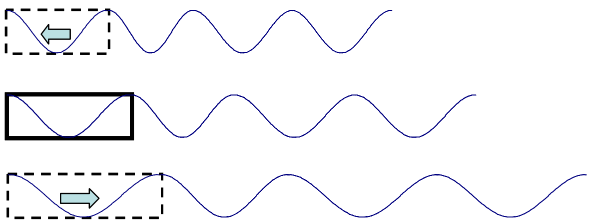


Figure 17 Tasks are modeled as waves in Planalyzer method

In quantum mechanics the probability of a certain outcome can often be calculated with very generic knowledge of inputs. In project schedules, task durations are often not defined with very high accuracy. There are many non-physical factors acting on the system of scheduling that cannot be easily perceived with the classical approach. One interesting feature of quantum modeling that can be applied to scheduling is that tasks performed by humans are not constant over time, but instead are performed in a way that can be modeled using linear combinations of harmonics. Many different factors affect the outcome, but are often difficult to measure precisely. Therefore, a quantum approach would be a solution for these uncertainties. (Hoglund, 2006)

Planalyzer tries to provide an answer to the question: “If particular tasks slip from the original schedule, what impact will it have on meeting the originally planned milestone?” The model does not answer the question: “What is the probability that a particular task will slip?”

In quantum mechanics elementary particles are presented by waves and in Planalyzer the wave function for each task is defined

$\psi \sim \cos(2\pi Nt/T+\varphi)$,

where t = project time, T = task duration, N = number of wave periods in T, and φ = task phase relative to the milestone.

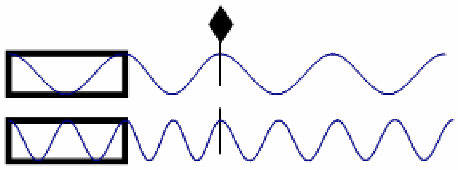


Figure 18 Tasks waves in Planalyzer

In Figure 18 two tasks are presented. In the upper one there is one wave period in the task duration and, in the bottom one there are two wave periods in the task duration. Waves are in the same phase at the milestone point (♦) (maximums).

Planalyzer is based on the quantum mechanical feature, interference of amplitudes. If the system (milestone) wave function is:

$\psi=\psi_1+\psi_2+\psi_3+\ldots=\sum_n \psi_n$ (summation occurs over all tasks associated with the milestone),

then the probability density P is:

$$P=|\psi|^2=|\psi_1|^2+|\psi_2|^2+|\psi_3|^2+2\psi_1\psi_2+2\psi_1\psi_3+\ldots,$$

and mutual coherence between the individual wave functions ψ_i defines the output. (Fishman, 2008)

In Planalyzer, tasks which are on schedule are interfering and coherent (superimposed in-phase) with the planned milestone and create a strong peak of probability density. If the task slips from the planned duration, it will result in phase shift and loss of coherence which leads to a reduction of probability. The central peak of probability density pattern in Figure 19 has width Δ and it characterizes minimum uncertainty of the milestone date. (Hoglund, 2006)

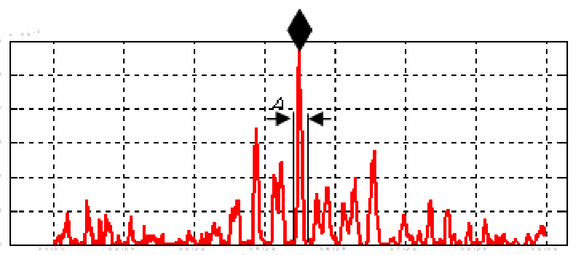


Figure 19 Probability density and milestone uncertainty

Width of milestone uncertainty Δ implies that task durations are defined with the accuracy of Δ. Plurality of project samples is created by Monte Carlo simulation where Planalyzer considers task durations symmetrically distributed around their start and finish dates. Task wave functions behave like $\cos(2\pi t/T_k)$ at the milestone point and, on the both sides of the milestone the probability density quickly oscillates. Interference of wave functions with random periods generates noise-like behavior. (Fishman, 2008)

Figure 20 shows comparison of classical (pink) and Planalyzer (purple) probability densities and cumulative probabilities (classical = black, Planalyzer = brown). The planned milestone date is shown by an arrow. As can be seen, wave presentation changes the probability density, but the S-curve is rather similar to the classical approach.

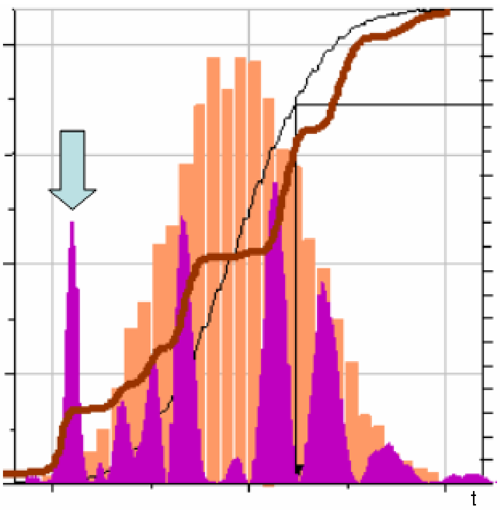


Figure 20 Comparison of classical and Planalyzer probabilities

Fishman (2008) argues that when uncertainty of tasks is introduced, the peaks of the probability density are stretched to later dates. From Figure 20 it can be noted that the expected milestone dates predicted by both models are very close to each other. Probability tails before and after the milestone are caused by the wave nature of the tasks interfering at the milestone. This is a typical effect showing uncertainty of the milestone date caused by uncertain durations of the tasks. Multiple probability density peaks are typical for quantum calculations with a small number of tasks. If the number of project tasks is higher, the frequency of Planalyzer method is higher, which leads to distribution approach classical results.

3.2.3 Metrics

When projects become large and more complex, it becomes more difficult for a project manager to get an understanding about the structure of a project schedule. Long-duration tasks that are scheduled to complete close to the milestone and long chains of dependent tasks are examples of structures which affect success. Relatively small slips in these tasks can cause milestones to be missed. Planalyzer evaluates the project schedule based on different structural aspects. The analysis includes three specific metrics, which try to specify the impact on milestones. The metrics are provided for each milestone and they are called visibility, probability (as a function of task tolerance), and task priority (in priority order in terms of ability to affect milestones). When these metrics are within expected limits, the schedule is considered to be well-constructed from the point of view of meeting the milestone dates. (Hoglund, 2006)

Visibility can be understood from Figure 21. Hoglund (2006) describes that there are two schedules presenting the same work, using the same amount of resources over the same planned time. From a project manager's point of view the bottom schedule is better because the manager can better monitor completion of tasks at the end of the project. In the bottom schedule a project manager can assess the project progress in mid-April and in late June. The advantage of this schedule is that the progress can be assessed and reported closer to the planned milestone. The manager is said to have better visibility in the second plan. In the top schedule, if the first task slips, a manager would know that in early March. Early May, is the next opportunity to check progress but after this, there are no further chances to assess the progress. The last task is long and results can not be seen before the final milestone in late July.

According to this example there is no visibility into the plan after May. A well-scheduled project should have no parts where visibility is low, especially just before the project is scheduled to be completed.

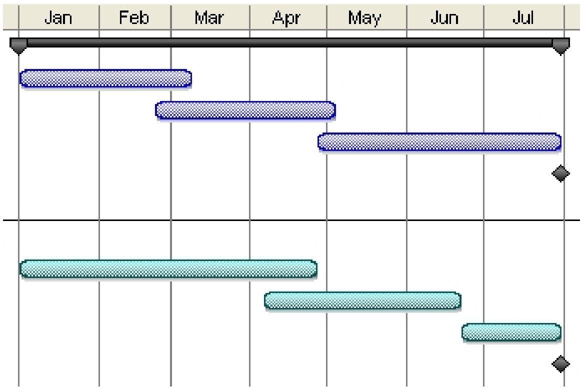


Figure 21 Visibility of schedules

Probability is defined as a task tolerance which is the average amount the tasks in a chain may slip before they will affect the milestone. It does not describe how much a specified task may slip but is intended to be a relative measure of plan robustness. High values of task tolerance indicate a schedule that will tolerate more change and low values suggest the schedule be revised frequently. Figure 22 indicates the expected probability of meeting the planned milestone, plotted against expected task tolerance. From the chart it can be seen that for task tolerance of two days, the expected probability is better than 80%. If the probability falls to zero on small task tolerance, the schedule will need frequent re-planning. If the milestone date is moved out, and probability curve only improves slightly, it means that the schedule needs to be reviewed carefully before implementation. (Hoglund, 2006)

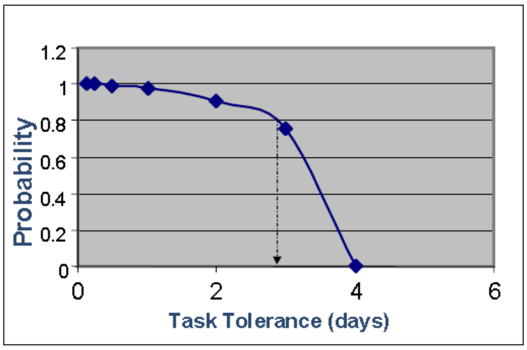


Figure 22 Task tolerance

Task priority indicates those tasks which, if they slip can cause the greatest potential slips in milestones. Assessing projects based on schedule structure does not depend on knowledge of the tasks: however, all tasks are not equal. In Figure 23 the top schedule shows a task completed well before the milestone, whereas the bottom schedule shows the same task completed on the milestone date. Considering meeting the milestone date, the bottom schedule seems riskier, even though the tasks are the same. (Hoglund, 2006)

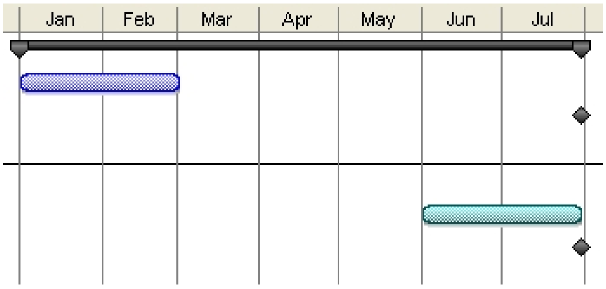


Figure 23 Task position affect task priority

Figure 24 shows a part of a sample project schedule. The metrics presented above can be utilized in assessment of the structure of that schedule. In Figure 25 two curves are plotted presenting task priority and task visibility of the sample schedule.

Task Name	Predecessors
Milestone 1	2,3,4,5,6,7,8,9,10,11,12,13
Task 1	
Task 2	1
Task 3	2
Task 4	
Task 5	
Task 6	5
Task 7	6
Task 8	7
Task 9	Milestone 2
Task 10	9
Task 11	10
Task 12	8,11
Task 13	12
Task 14	
Task 15	
Task 16	
Task 17	
Milestone 2	14,15,16,17

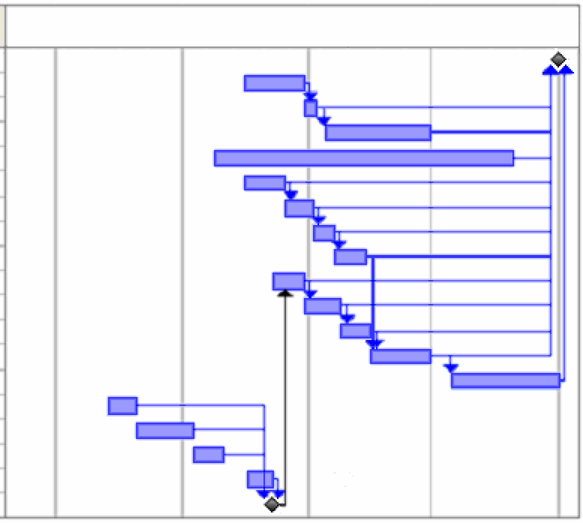


Figure 24 Sample schedule

The red curve in Figure 25 shows the relative contribution of each task's effect on the milestone date if the task slips (task priority). In the sample schedule, Task 4 and Task 13 indicate higher values. This can be seen from the schedule structure because these tasks are closest to the milestone, thus, a slip in these tasks has the most effects. In the sample schedule, Task 5 and Task 9 are indicated to have the highest visibility (black curve). Both these tasks start a series of tasks that depend on either Task 5 or Task 9 being completed. If a task indicates high values in both curves, then it is logical to have close management of that task.

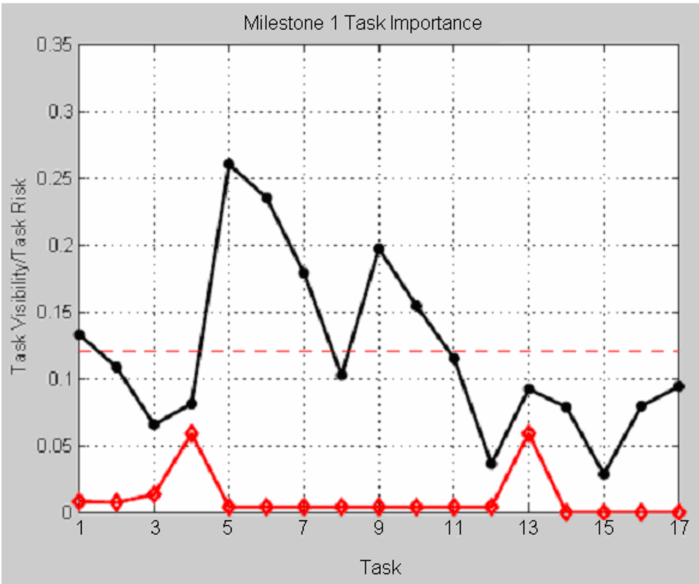


Figure 25 Task priority and task visibility

3.2.4 Applications for Scheduling

What makes the Planalyzer method interesting is its ability to calculate probabilities and S-curves from the schedule structure without any additional inputs. In Planalyzer the role of empirical inputs is tried to kept to the minimum and only by defining cumulative risk factors can the analysis be affected. With Planalyzer the milestone probability can be evaluated fast (10-20 minutes) compared to interviews and definition of task duration distributions required for classical analysis. (Fishman, 2008)

Fishman (2008) suggests that at the planning stage of the project, both the classical and Planalyzer approaches should be used in parallel. Comparison of results enhances confidence in the project evaluation and if two models show different results, the discrepancy between them will stimulate more in-depth analysis of schedules.

At the execution stage the schedule analysis is different. With the classical approach it is difficult to assess schedules because they are under constant change. In Planalyzer the uncertainty is attributed directly to the milestone, not to the individual tasks, thus, changes in the structure do not affect the evaluation process. The simplicity of the Planalyzer method would motivate project managers to compare schedules under continuously varying conditions and thus accumulate better project scheduling data than are currently available. (Fishman, 2008)

The Planalyzer method of assessing project schedules is a quantitative way of evaluating schedule structure and has shown to be consistent with current other practices. The method automated by software tools can be used as a quick check of schedules, allowing project managers to focus attention to the tasks most likely to affect milestones. (Hoglund, 2006) Different phases of the analysis and the results of case company schedule evaluation are described in the empirical part.

3.3 Synthesis from Literature Study

This section presents the findings from the literature study. Based on these findings, a framework for schedule quality criteria is proposed. This framework is used in the empirical part to assess the case project schedules and current scheduling practices of case companies.

The literature studied revealed the extensive research done in the field of project management, planning, and scheduling. The historical insight showed that methods developed nearly a century ago are still in widespread use, but not many new approaches have appeared in daily practice. Planning processes, scheduling methods, and critical success factors are specified in the professional literature by several authors. Software packages supporting project management and scheduling tools facilitating schedule development have improved and are widely used in project companies. Although new methods and techniques for scheduling have been introduced by researchers and academia, they have not been transferred and diffused into standard practices of project management.

In many publications project scheduling practices are described to proceed according to the scheduling process. Generally, it is thought that if scheduling is performed in accordance with different stages of the process then the scheduling will produce the desired output. Project scheduling is seen as a multi-stage decision process including various methods, techniques, formats, and different software tools intended for that purpose. The importance of time management is widely recognized and a realistic schedule is defined as a critical factor for the success of projects in many studies. However, methods for assessment and studies concentrating on evaluation of schedules and scheduling are scarce. No clear definition or framework of how the quality of project schedules can be assessed was found from the literature study.

As Herroelen (2005) has indicated in his study, many surveys conducted in project management reveal that the gap between project scheduling theory and project management is still wide. Nowadays, projects are often subject to expansion of time and cost, and lack of appropriate planning and control are often major reasons for escalated projects. The reason for the problems is that the scheduling methods published in the open literature have not yet found their way into commercial software tools and those are rarely used by project schedulers. Different project management information systems for project planning are mainly used for communication rather than for optimization of schedules.

Zwikael and Globerson (2004) have claimed that there is a lack of models for evaluating the quality of planning. Their model Project Management Planning Quality (PMPQ) is intended for evaluating the quality of project planning. In the PMPQ model, scheduling is one of the nine project knowledge areas, and it is subdivided into four planning products. The intensity of the use of project activities, PERT or Gantt charts, activity duration estimates, and activity start and end dates is evaluated. These products are assessed by how often they are used (hardly ever…always) to obtain the number value for quality of time planning.

As can be noted, the PMPQ evaluation does not reveal much about the quality of the schedules. If project activities with duration estimates, and start and end dates indicated in a Gantt chart are always obtained, this does not mean that the quality of the schedule is high. Usually, these items are self-evident in the scheduling process.

3.3.1 Scheduling Combined with Project Implementation

Based on the literature analysis, a model of scheduling is proposed in Figure 26. It emphasizes the meaning of a schedule in a “scheduling – project implementation” process. Various factors affect the scheduling process. Usually, the scheduling is managed by project management. The schedule can be considered as a product of the scheduling process. In most cases, the same project management manages the project implementation phase, where the schedule produced works as a tool for project management. As can be seen from the figure, the project management first affects the scheduling process, which is producing the schedule, which in turn affects the project management. The schedule is used as an intermediate product in the production of the final product for the entire process.

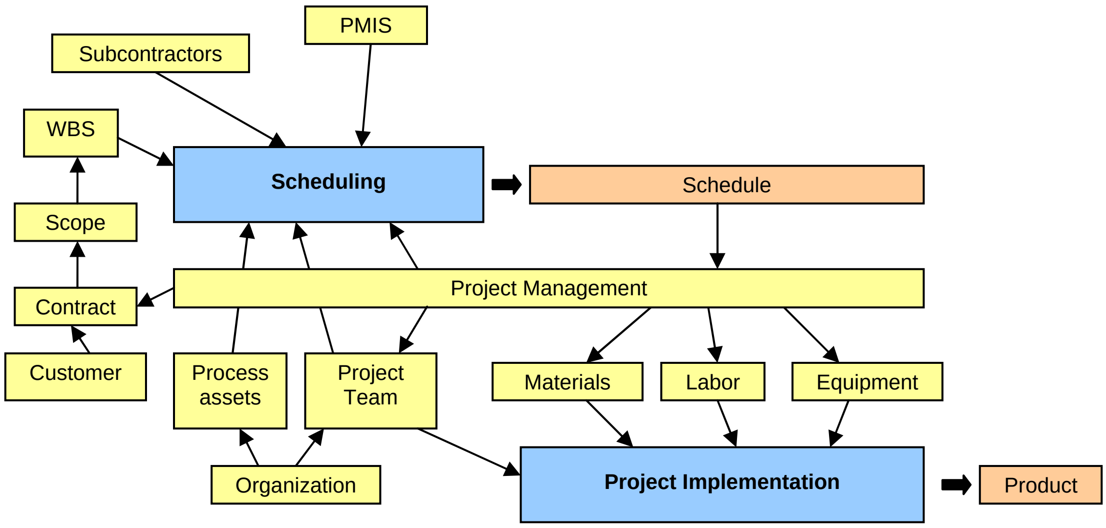


Figure 26 Scheduling combined with project implementation

(**Process assets** = policies, procedures, and guidelines for conducting work and organizational corporate knowledge base for storing and retrieving information)

When considering the evaluation of a project schedule based on the model in Figure 26, factors which will affect the scheduling, as well as how the schedule will affect the factors and processes after its production should be taken into account. Schedule quality is only as good as the quality of the input factors. A well-performed scheduling process is not enough to produce a high-quality schedule if the factors which affect scheduling are not on an appropriate level. Poorly-defined scope and WBS will certainly hamper the scheduling process. The readymade schedule will affect various factors and actors. The quality of the schedule and the way it is communicated to the stakeholders are connected strongly to its level of usage. The impact of schedule quality is discussed in the next section.

Numerous factors affecting scheduling complicate the evaluation of a schedule. A poorly implemented PMIS or inexperienced project team will probably lead to low schedule quality, while high quality is not guaranteed if these factors are corrected. In addition, the problem becomes even more challenging when considering different kinds of schedules in different project phases. Although the schedule can be judged to be of high quality, the project management practices can still affect the success of the project.

Kog et al. (1999) have pointed out that many research efforts have been aimed at improving scheduling techniques and to enhance the reliability of schedules. Nevertheless, improved scheduling techniques and better schedules can not assure timely completion if they are not used together with appropriate project management inputs. Laufer and Tucker (1987) support that argument, indicating that advanced scheduling models can not guarantee good results because schedules are primarily intended for forecasting, not for the role of execution. The same can be applied to advanced scheduling techniques which also act in a merely supportive role in managerial endeavors.

3.3.2 Impact of Schedule Quality on Project Success

Although the schedule is defined as a critical success factor of projects, the way it causes the effects is not usually described. Raymond and Bergeron (2008) have introduced DeLone and McLean's information systems success model (ISSM) and Davis et al.'s technology acceptance model (TAM) and adapted these to understand the impacts of PMIS on project managers and on project performance. I have adapted the model of Raymond and Bergeron further to verify the impact of schedule quality on project management and project success. The model in Figure 27 is composed of five constructs, namely, the quality of a schedule, the quality of schedule information output, the use of a schedule, the impacts on project management, and project success. The factors are connected to each other with arrows, and connections are described as follows.

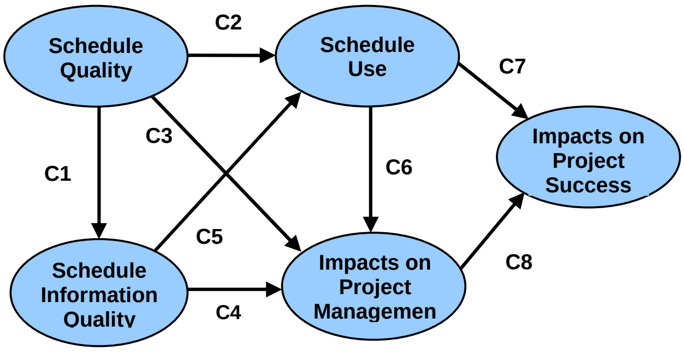


Figure 27 Schedule impact on project success

Connection 1: Better schedule quality is associated to better quality of information output (availability, relevance, reliability, precision and comprehensiveness).

Connection 2: Better schedule quality is associated to greater use of schedules. Good schedule quality positively influences willingness of use.

Connection 3: Better schedule quality is associated to greater impact on the project management. Higher schedule quality positively affects project management's decision making.

Connection 4: Better quality of information output is associated with a greater impact on the project management. How the schedule information output is formatted and communicated impacts project management.

Connection 5: Better quality of information is associated to greater use of schedules. If the quality of information output is high, it increases users' trust of the information.

Connection 6: Greater use of schedules is associated to greater impacts on the project management. Increased use of schedules has a positive impact on the project management in terms of better performance of users and in support of decision making.

Connection 7: Greater use of schedules is associated with a greater impact on project success.

Connection 8: Greater impacts of schedules on the project management are associated with greater impacts on project success. Projects led by more efficient managers, due to their use of high-quality schedules, tend to be more successful in terms of meeting schedules, budgets, and specifications.

Better quality of schedules and, thus, quality of information output increases the opportunity of schedules to be used, which in turn allows the process to have a positive impact on the project management. Quality of information output leverages the project manager’s work as a professional if the manager has access to schedule information of high quality and he or she uses schedules more intensively and more extensively for planning, controlling, monitoring, and reporting activities. A combination of quality information and extensive use of schedules allows a project manager to feel more effective and provides better support for decision making. Schedule quality has no direct influence on project success, but it is only through the quality of information output, the extensive use of schedules, and impacts on project management as was presented also in Figure 26, where scheduling was combined with project implementation.

3.3.3 Criteria for Evaluation of Schedule Quality

Zwikael and Globerson (2004) as well as Laufer and Tucker (1987) have claimed that the evaluation of planning quality and effectiveness is difficult to accomplish and that there is no model available for that purpose. The assessment of schedules is problematic because the results are not only dependent on the quality of scheduling, but also on the quality of many other factors and managerial activities. Schedule performance becomes apparent only after the project has started and usually when something is going wrong.

Based on the reviewed literature, criteria are collected that characterize the quality of the project schedule in Table 5. The criteria are divided into two levels: high and detail. Higher-level criteria are more ambiguous and one of each can capture many of the detailed criteria that are more specific and descriptive. For example, almost all detailed criteria in the list can be seen as characteristics of a feasible schedule, which is a higher-level criterion. Usually, when describing criteria for a good schedule, higher-level criteria are mentioned first. Higher-level criteria are difficult to quantify and evaluate, especially if the evaluation is performed before the project schedule is taken into implementation, making it impossible to compare the planned and actual realization. If a schedule is deemed to be realistic, it can be interpreted to mean that it is prepared based on the best knowledge available. However, that is still a very subjective assessment and impossible to quantify for measurement.

Table 5 Criteria for schedule quality

<table>
<tr><th>Higher-level Criteria</th><th>Detailed Criteria</th></tr>
<tr><td rowspan="11">• Realistic
• Feasible
• Simple
• Make commitment
• Accurate
• Timely</td><td>• Tasks decomposed from WBS work packages</td></tr>
<tr><td>• Tasks with explicit names in logical sequence with right dependencies</td></tr>
<tr><td>• Duration estimates based on evaluation and previous experiences</td></tr>
<tr><td>• Same detail level in each schedule to provide a basis for measurement and control of progress</td></tr>
<tr><td>• Provide understandable and usable information to those who use it</td></tr>
<tr><td>• Identify critical path as well as critical tasks</td></tr>
<tr><td>• Tolerate variation, easily modified and updated</td></tr>
<tr><td>• Enhance communication between project stakeholders</td></tr>
<tr><td>• Traceability between hierarchy levels</td></tr>
<tr><td>• Conform to resource availability</td></tr>
<tr><td>• Include buffers which are inserted at the right places</td></tr>
</table>

Although the detailed criteria are more specific than higher-level ones, the assessment and evaluation is subjective and depends on the assessor's viewpoints. Some of them can be easily quantified, while others can not. It is much easier to assess whether buffers are inserted in the right places, but enhanced communication is more problematic to measure. For example, to measure easy modification, there should be clear parameters that indicate how the easy modification is defined, otherwise the evaluation becomes fuzzy and biased.

The framework will be used in the empirical part of the study to analyze the scheduling processes and schedules of case companies. After the interviews of case company representatives and analysis of case project schedules, the framework will be adjusted if needed. Acquired information of schedule analysis and case company scheduling processes will be used to improve the model. Finally, the suggested criteria of the framework will be described and specified.

The reviewed literature of the Planalyzer method indicates that it is an interesting tool for schedule evaluation because it does not need any additional inputs to the schedule. In addition, it is easy and fast to use. Different factors affect the probability of reaching individual milestones and therefore, the probability of the entire project being completed on time. These factors are strongly related to the schedule structure and can be quantified and measured, but the criteria presented earlier in this section are more complex in that sense. The different steps of Planalyzer analysis will be presented in the empirical study. Together with the presented evaluation framework, Planalyzer will be utilized to evaluate the schedules of case projects followed by a more detailed description of the results.

4 Analyzing the Quality of Schedules in Case Projects

In this chapter the findings and results of the empirical study will be discussed. It will begin with a description of the research methods used, followed by introduction of Planalyzer use. Then the case companies and case projects are presented. Scheduling practices which are currently used in the case companies are investigated and then the schedules of case projects are assessed and compared in the cross-case analysis. Finally, suggested managerial implications are presented.

Empirical study will mainly concentrate on pre-implementation and during-construction scheduling because all the case projects were ongoing. The schedules which were prepared in the early phases of the projects have been developed further during the project. Instead of feasibility and tender phase schedules, the more detailed construction schedules are suitable for the study.

4.1 Research Method

Interviews were conducted in the case companies as semi-structured and tape-recorded. Before the interviews, project schedules and other descriptive material of one ongoing project of each case company were requested. The content of the study was presented to companies with the introduction letter (Appendix B). In addition, received materials were studied before the meetings to try to find schedule problems that could be clarified during the interviews. The interviews were divided into two parts: the first part was conducted by asking semi-structured questions (interview outline in Appendix C), and the second part was used for presenting the analysis tool and correcting the schedules to the right format for the analysis.

The main purpose of the interviews was to get knowledge of current practices of project scheduling in industrial delivery projects. One aim was to get insight into how the case companies understood the quality of project schedules and, whether they felt that the quality of schedules was on an appropriate level. In addition, the interview situations were a good opportunity to present the analysis tool used and to get first impressions of company representatives whether it was useful for the study.

The first part of the confidential face-to-face interviews with the project managers or schedulers lasted for about an hour. The interview focused on scheduling in general in the case company and then more on the specific project. It was practical to study ongoing case projects, so that the interviewees had the project events clear in their minds. The second part, which was used to present the analysis method and going through the case schedule, took about 30-60 minutes depending on how much attention the schedule needed. If there were too many errors, it was discussed whether the responsible person for scheduling would do the necessary corrections later on, or whether the schedule would be left out of Planalyzer analysis.

4.2 Planalyzer in Use

Planalyzer was used to evaluate the project schedules of case companies. Some companies were using Primavera instead of Microsoft Project, thus those schedules could not be considered.

Planalyzer can be installed as an add-on feature to MS Project. The version of MS Project must be 2003 with Service Pack 2 or later. Other additional components (MSVC 2005 Redistributable, Microsoft Office 2003 Web Components) which are needed for proper use can be downloaded from Ibico's Web page. When starting MS Project the first time after the installation of Planalyzer, the pop-up window will show where the tool can be found and how it can be started. When Planalyzer is selected it appears as an adjustable sidebar on the left side of the MS Project window. To get Planalyzer to work properly time settings of the operating system must be changed to US mode (month/day/year). Otherwise the schedule calculations can not be performed due to wrong date format.

Planalyzer analysis is divided into three different phases which are presented in the following.

The First step of Planalyzer is a file check which verifies the project schedule for task mis-assignments, orphan tasks, and empty milestones. A mis-assigned task is one whose date has finished beyond the milestone to which it is assigned, or is associated with tasks or milestones which are not included in the file. An orphan task is one that has no association with a milestone, although it might be a successor or predecessor of other tasks. A problem in many schedules is that long chains of tasks may end with no final connection to a milestone. An empty milestone is one that contains less than two tasks. A milestone that contains only a single task is not considered a legitimate milestone because in analysis they are indistinguishable from a single task. In the analysis, all zero- and one-task milestones are ignored. A task reporting to the milestone is not ignored as long as the task also reports to a later milestone.

All these tasks which contain errors are ignored in further schedule analysis so they must be fixed before any serious analysis is attempted. For key milestones, it is important that all the necessary tasks report to these milestones. Major milestones can be comprised not only of direct tasks, but a number of reporting milestones. Adding a new task or deleting an old one can easily cause an unintentional break in the line of successor tasks to the milestone. All tasks should have at least one successor and predecessor.

When task assignment errors have been corrected, the schedule must be saved before running file check again.

The Second step is risk climate setting, where the estimates of resource, scope, technology maturity, and communication/coordination risks are assessed (1 to 5) for the project. Based on these input values, a relative risk factor is derived, which varies from 1 (low risk) to 10 (high risk). The risk factor indicates that with a low risk any schedule is feasible with high probability, but with a high risk, few plans can be completed on schedule. If values are kept on default 3, only well-designed schedules have a high chance of success.

The Third step is project analysis and, when clicking "Analyze your Project", all tasks in the project are perturbed. Task perturbation means that tasks are intentionally slipped by a range of predetermined amounts. Structural probability and milestone uncertainty for all milestones with more than 10 tasks reporting is calculated. Low probability results indicate structural problems in the schedule. The basic assumption during the analysis is that all tasks are uncertain because of human productivity. This is the key idea in Planalyzer because tasks which have not been repeated many times and have not become routine, are difficult to estimate due to human performance.

When the schedule is analyzed, Planalyzer provides a list of milestones and whenever a milestone is selected, a pop-up with analysis options is made available for selection, as shown in Figure 28.

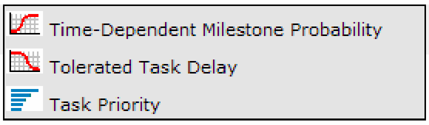


Figure 28 Planalyzer analysis options

Time-Dependent Milestone Probability graph shows the effect of date slip. The graph indicates the cumulative probability of meeting the planned milestone at different completion dates. If a milestone is comprised of many independent tasks, the shape of the curve will approach an S shape like in S-curve. Some projects have that kind of task dependencies that the curve is not symmetric and particularly if the number of tasks reporting to the milestone is not large. The curve indicates the following issues from schedules.

- If project probability of 100% is reached long after the planned milestone, this implies planning problems. This can be a consequence of long chains of sequentially-dependent tasks, so that any slip in an upstream task can affect later tasks.
- If the scheduled milestone date indicates low probability for the planned date, but high probability a short time later, this suggests that the schedule needs buffer time equal to the shift in time to reach high probability.
- If the project probability is 100% early before the milestone, then there is slack included in the schedule. This can be due to buffers which are inserted in the schedule, but if buffers are included in the task durations, they can not be taken into account in the analysis.

Tolerated Task Delay graph shows the sensitivity of a project schedule to task slip. A well-designed chain of tasks ending in a milestone is considered robust if the milestone can tolerate reasonably large average delays. The milestone is referred to as brittle if even small average slips cause the date to be missed. The average slip is the same as the milestone width. It is necessary to manage tasks better than the average slip in order to meet the milestone date.

Task Priority graph indicates an ordered list of the 10 tasks by priority that can most affect the probability of meeting a milestone date. It is a list of tasks, which individually can have the biggest impact on a milestone date. In a well scheduled milestone, there should be only a few tasks that show high risks relative to the average.

The graph of prioritized tasks is calculated by sequentially perturbing each task to calculate its impact on the probability of a milestone. Task rankings are relative to one another and results are scaled to an average task. The contribution of different tasks to a milestone is not equal because some tasks with a small slip can have much larger impact on milestone completion. Often, there are only a few tasks that affect a milestone, while others have effectively no contribution.

The results of Planalyzer evaluation of case project schedules will be presented in the following sections. The steps introduced above and graphs will be demonstrated during the analysis of real project schedules.

4.3 Introduction to Case Companies

Case companies were selected among Finnish project-based companies. Some of them were participating in the GPS II programme and expressed their interest in this study. All case companies were implementing large-scale industrial delivery projects in different parts of the world. Companies are referred to as Case Company A, B, C and D throughout the text to ensure confidentiality.

All four case companies are executing engineering projects where goals and methods are well-defined (Turner and Cochrane, 1993). Often, in such projects, the actions are well-defined so hard methods are in use. Emphasis is on planning and control and effectiveness of the process. The projects are engineering, procurement and construction type (EPC). All others, except Case Company C, are main contractors and responsible for the entire supply of the project. Such projects are also called turnkey projects, which are constructed by a developer and delivered to a buyer in a ready-to-use condition. Case Company C is working as a client’s consultant in a construction project. For the client, it means that they have a single contact partner and they do not need to create separate organizations for handling project interfaces. Project information of different case projects is presented in Table 6.

Table 6 Project information

	Case Company			
Project Information	**A**	**B**	**C**	**D**
Project type	EPC	EPC	semi-EPCM (mere equipment supply by main contractor)	EPC
Product	Power plant	Substations	Paper mill	Boiler island (power plant)
Destination country	Germany	Zambia	Poland	Finland
Supply time	78 weeks	80 weeks	104 weeks	146 weeks

EPC project service usually includes project management, configuration of scope, detailed engineering, procurement and manufacturing, delivery of the contracted scope, construction and installation services, commissioning, start-up and management of the construction site. In some contracts the supplier can take care of the maintenance of the entire plant after the start-up. EPC supply means a project with fixed dates, tight schedules, and contracts which can cause substantial penalties.

In the planning of EPC delivery projects several things must be taken into account. The main issues to consider are the time period, target country, different subcontractors, technical requirements and the contractor's own resources. The project's structure begins to take form in the preparation of WBS, where the project is divided into distinct levels. On the top of the WBS hierarchy is the main level, which is divided into sublevels (usually engineering, procurement, civil works, installations and commissioning). Based on the WBS a master schedule with main milestones is prepared at the beginning of the project. As the project proceeds, more detailed schedules for different areas are prepared.

4.4 Scheduling in Case Companies

4.4.1 Case Company A

The Case Company A is a company providing power solutions on EPC basis. It delivers power plants with an output range of one to hundreds of megawatts. The plants are designed by modular technology, which means a short delivery time and ease of later expansion. In most cases the construction phase overlaps the design phase because projects are fast-track turnkey projects which must be completed in the earliest time.

In this case project, Case Company A is supplying six turnkey power plants to Germany. The start of the construction had already been postponed in the very beginning of the project because of the long time taken in processing of construction and operational permits by the local authorities. Nevertheless, the contractual time started to run not until all the permits had been issued. That delay allowed more time for planning and preparation of the project. Case Company A did detailed engineering in the meantime and was able to reduce the workload from the rest of the project.

The master schedule is on the top of the hierarchy of schedules in Case Company A. It is the roughest estimate and the first schedule established by the project manager at the very beginning of the project. The master schedule works as an overall performance evaluation tool for monitoring the progress of the entire project. Tasks listed in the schedule are main activities and every power plant contains approximately 20 main tasks which are broken down into sub-tasks in more detailed schedules.

The master schedule is used to coordinate inter-relationships between different project components and direct the execution of works at the highest level. It works as a support for communication between Case Company A, the customer, financiers and other project stakeholders as well as an internal tool. The main purpose is to give a good picture of the whole project with few tasks. The master schedule is intentionally done roughly and in an easy-to-understand manner so that stakeholders with no understanding of technical aspects of the plant construction can understand the schedule. Typically, all major decision points and contractual milestones are defined in the master schedule and they can be easily communicated due to the relatively small number of other tasks.

The master schedule is developed during the project planning phase in order to establish a baseline. When the project is proceeding in the implementation phase, the progress is updated to the schedule and compared to the baseline. The updated master schedule is used for reporting to the customer and it is attached in the monthly reports.

The master schedule is formulated based on experience and it is realistic but tight. The total time frame in the schedule is only two-thirds of the contractual completion time. Leftover time is used as a buffer at the end of the project and if the works are prolonged the buffer can be consumed to prevent exceeding the contractual time. The buffer is not informed to the subcontractors, but the project team is aware of it and it will be used only as a safety buffer if the works take longer than planned.

The next schedule in the hierarchy is the *engineering and procurement schedule* which is a milestone schedule. It is usually adapted from a standard template. It is based on the project scope and synchronized with the master schedule to enable traceability. The engineering and procurement schedule is prepared for internal coordination after the master schedule. The project manager coordinates the preparation of the schedule with the design, procurement and logistics specialist of the project team.

The most detailed schedule prepared by Case Company A is the *installation and commissioning schedule*. It defines all the activities which are performed at the construction site and every site has individual schedules. If the plants are similar to each other the schedules for different plants can resemble each other in most parts. Installation and commissioning schedules are prepared by the project team of Case Company A in the design face before the site implementation begins. The project team consists of specialists of different fields who compile the schedule in workshops. The framework for the schedule is often taken from similar previous projects and modified to fit the current project.

As a main contractor Case Company A can demonstrate the installation and commissioning schedule as a base for discussions with sub-suppliers and subcontractors. The schedule facilitates allocation of task sequence, critical path, and time frames for subcontractors in negotiations. Subcontractors will provide installation schedules of their own parts to Case Company A which will add them to the main installation and commissioning schedule. Each subcontractor is responsible to provide a detailed time schedule of their works in the correct format which can be combined with the schedules of Case Company A.

The installation and commissioning schedule works as a progress follow-up tool for site works as well as an agenda for site meetings. All the completed, ongoing and upcoming tasks are followed according to this schedule and the progress is updated in the meetings on weekly basis. Tasks of the installation schedule are not linked to upper tasks of the master schedule although they must be within the time frames which are allocated in the master schedule.

In addition to the above-mentioned schedules, Case Company A is using more detailed schedules e.g., a schedule of heavy lifts and subcontractors' detailed schedules (work plans) which are not integrated with the installation and commissioning schedule.

Considering project scheduling in Case Company A in general, the project manager stated that the organization should have persons who have good knowledge of plant construction as well as understanding of scheduling methods and its tools. One person could manage the whole scheduling process and handle the schedule as an entirety. A good schedule is usually established by a small group of experts of different areas which are coordinated by one person. The team's effort is invaluable, but the compilation of a schedule would be easier if one responsible person could handle it.

The biggest problems of scheduling are in large EPC projects. The complexity of the projects affects the management which has influence on time management. Scheduling will be affected if there are other uncertain issues which disturb the project. Internal activities are usually clear but the operations performed by sup-suppliers and subcontractors are often too fuzzy and incorporating them in the schedules causes much bother. Additional work with schedules encumbers project employees who don't have enough time for them. Formulating a schedule requires time and lack of it hampers the process to develop routine for scheduling.

The main problem in scheduling is the lack of attention to schedules after they are created. The credibility of old schedules that have not been updated quickly disappears among the employees and they are not willing to put any effort to perform works according to the schedule. Attitudes towards schedules in the organization are fairly negative because the common opinion is that the schedules produced are not useful and reliable. When the schedules are not on an acceptable level the project workers are not able to use them in their everyday work. Construction workers at the site are used to working in the same way as before and “Work takes the time it takes” is a common mentality.

Project schedules are seen as basic tools of project management, and almost all work in a project is coordinated by schedules. However, the schedules are not analyzed at the end of the project to gather valuable information of how well they have performed. Also, the tacit knowledge of scheduling often stays within the project team and it is not distributed well after projects.

MS Project is the only scheduling software tool used because of its wide usage in the industry. Case Company A is not using any advanced features of MS Project. Resourcing is not in use because most of the works are performed by subcontractors. It would be too troublesome or even impossible to attach subcontractors’ resources to the main schedules.

The project manager claims that a feasible schedule is seen as the best way to bring all actors together and motivate them collectively and it works like a backbone for the entire project. The fastest and most clear way to start communication with project stakeholders is with a clear view of the schedule. Everybody in the organization and all stakeholders must commit to making a good schedule. All the know-how of individuals and organization of the plant construction can be included into a project schedule. A schedule is the only way for a project manager to understand the events of the entire project.

4.4.2 Case Company B

Case Company B is a manufacturer and supplier of electrical goods and services. In this case project it is supplying several turnkey substations to a mining company to Zambia. Case Company B has supplied substations before also to Zambia, which makes the preparations easier. The project is a turnkey supply done on EPC basis and the supply time is 68 weeks. The project will be completed about three months late from the original plans.

In Case Company B the *master schedule* is on the top of the hierarchy of all schedules. It is based on milestones allocated in the contract and it is prepared when the project is transferred from the sales to the project department. Usually, there is a rough estimate schedule from the bidding phase which can be used as a template for the master schedule. The schedule for design is also established at the beginning of the project, but is a separate document and not part of the master schedule. The schedule for procurement and shipping of equipment and materials is included in the master schedule. Installation and commissioning tasks are in the master schedule but not very detailed because there is a different schedule for that purpose which is formulated later on for the site phase.

The master schedule is prepared with the coordination of the project manager by the project team and line managers. Contractual milestones create the timeframes for the schedule and it is often modified from a schedule of similar previous projects. The consultant for the project is the most important stakeholder outside the parent organization who is uses the master schedule for progress follow-up purposes. The customer is not interested in detailed tasks, but more on milestones where payments are due. An updated master schedule is provided once in a month to the customer and consultant in a monthly report.

The installation and commissioning schedule is prepared in more detail for controlling site activities. Time frames for installation and commissioning tasks are allocated in the master schedule and these tasks are divided into more detailed ones. Subcontractors are asked to provide their own schedules regarding their works but those are not added to the master or installation schedules. Weekly schedules for site operations are not done, but the installation schedule is detailed enough to be used for control purposes on a daily basis.

Every task in the installation and commissioning schedules has a task owner and every project worker knows which tasks or systems he is responsible for. The schedule works as an agenda for the site meetings and it is followed up and updated weekly. The coordination and control of the schedule is maintained from the site during the implementation phase. Often, there is too much other work at the site and schedules are not updated, which hampers the entire control process.

According to the project manager of Case Company B, the involvement of project team members in the preparation of schedules is very important and it creates commitment to strive for it. In Case Company B there is no need for person who is only dedicated for scheduling. A common view is vital and everybody is expected to express his own view in the planning phase. If the schedule is too tight and unrealistic, employees do not take it seriously. The project team and line managers evaluate how long the tasks will last and based on that assessment they do the task estimates. Experience affects task estimates much and project workers who have been involved in projects for a long time, give the most realistic estimates. Data of task durations are not collected or stored and can not be used as a help for estimating.

Projects which Case Company B is executing are not very unique and most parts are similar to previous projects. Country conditions in the destination and the customer's manner of performing things mostly affects processes and scheduling.

In Case Company B the main purpose of schedules is to facilitate controlling and steering of the project. The schedule is a basic tool for project management and it enables to deliver of project information to different stakeholders. The schedule is a way to connect different activities and stakeholders together. The project management can predict how the project is proceeding and based on that information corrective actions can be taken to improve performance.

The attitude in the organization to schedules is diverse and different levels have different views. It is self-evident to everyone to have schedules because without them the steering of project would not succeed. Contractual penalties need to be informed to the project team so that everybody tries to do his best to complete the project on time. The project management believes that it is motivating when everybody knows that the projects must be completed on the agreed date and success affects future projects.

MS Project is the only scheduling software used in Case Company B. MS Project is experienced as difficult to use and consuming too much time when formulating large schedules. Resourcing is not applied in the software because it would complicate scheduling even more.

Common evaluation or critical review of ready-made schedules is not performed with the project team. The lessons learned from the project are studied and realization of the schedule is compared to the planned one. Observations to the minutes are written, but this information stays mostly as tacit knowledge of involved project members. Often, it is said: "same mistakes were made again".

The project manager stated that a good schedule must be realistic, be controlled and maintained as well as bound to the contract. It works as a tool for communication for the entire project team. The schedule gives a backbone to the whole project. Lack of updating is seen as the main weakness of the scheduling process. Schedules needed to be followed up weekly, apart from monthly reports. Estimates which are too optimistic, missing tasks or missing parts are also considered as defects.

4.4.3 Case Company C

Case Company C is a global consulting and engineering firm focusing on the forest industry. It provides engineering and project implementation services for pulp and paper industry projects worldwide, maintenance engineering and other local services to the mills. In the case project, Case Company C is acting as a client's engineer in a paper mill project in Poland.

Project scheduling is well implemented in Case Company C. There is a systematic way of producing schedules in different phases of projects as can be seen from Figure 29. The level of detail of schedules increases as the project proceeds through development to implementation.

Project schedules are made by a team which consists of experts from different fields and led by schedulers who are specialized and dedicated only for schedule preparation. The scheduler coordinates the process and gathers information which is arranged and agreed upon in collaboration for common goals. The main purpose of schedules is to steer the project through the project's life cycle. Schedules are one of the most important tools of coordination for the project manager.

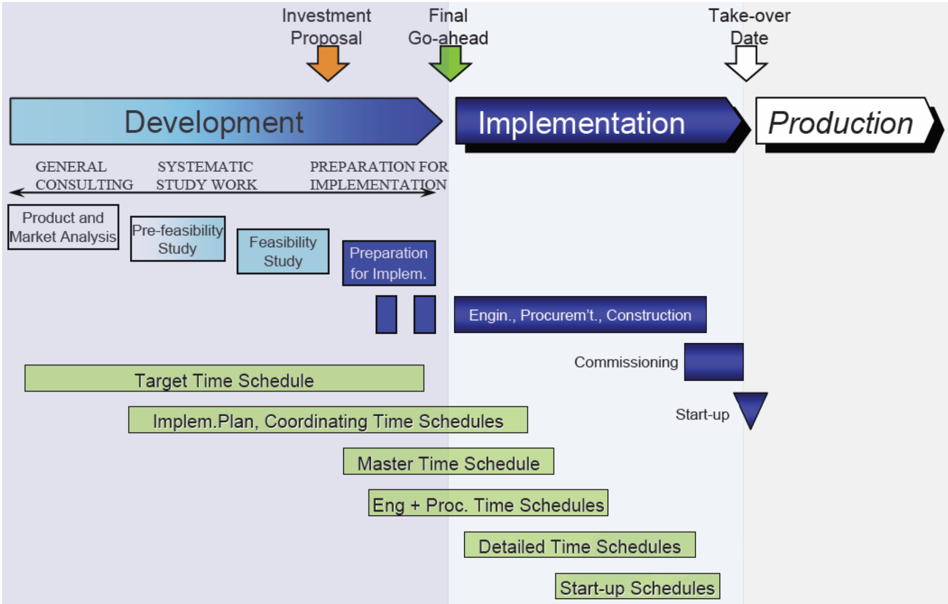


Figure 29 Time schedules of different project phases

Case Company C classifies different schedules by using the hierarchy of schedules which is presented in the Figure 30. In the early phases of feasibility study the schedules are more approximate, but when the project is proceeding to the construction phase the schedules are divided into smaller and more detailed ones.

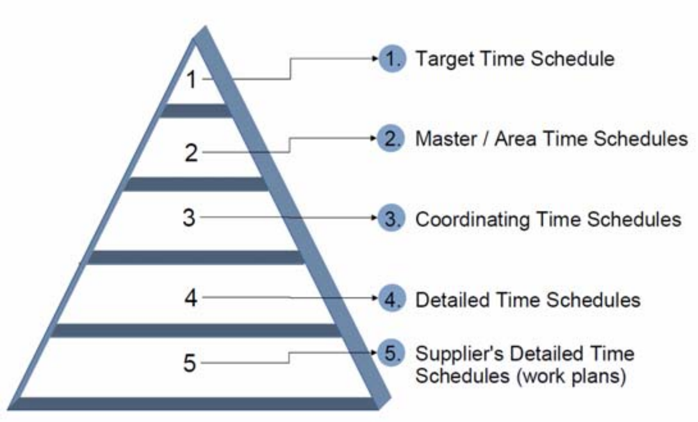


Figure 30 Hierarchy of time schedules

The Target time schedule is the first schedule issued in the project. In fact, Case Company C prepares a schedule before the target schedule for internal coordination of works which are included in the early stages of the project development process. The target schedule defines the overall framework of the project and also gives the total duration of time reserved for purchases, engineering, construction, and commissioning. The target time schedule gives the basis for the project's feasibility analysis. It provides the project management a tool to make estimates regarding project costs, required resources, market perspectives, and impact of weather conditions during construction. In the first stage, the target time schedule is based on the experiences of similar projects, adjusted to the actual case and chosen strategies. The target time schedule is the highest level reporting document to all stakeholders of the project.

The Coordinating procurement time schedule is made based on the agreed purchasing policy and it describes the main tasks for procurement for each project area. It provides the framework for the detailed procurement schedule so that the times in coordinating the construction and commissioning schedules can be achieved. The importance of good purchase control is not only for the delivery of necessary machinery or materials to the construction site. Many engineering tasks are dependent on the selection of a specific machinery type for certain functions or on receipt of design data from suppliers. There are three main criteria in procurement scheduling:

- When the engineering will reach the readiness to issue specifications for purchase
- When the purchased items are needed at site or in a workshop, and what are the estimated delivery times
- Whether the purchase has influence in design work, and when the data would be needed

Nowadays the longest supply time of main components mainly defines how long the projects will last. That sets the timeframes for the projects Case Company C works on.

Although the master and coordinating time schedules are on different levels in the hierarchy, in practice they are the same type. Usually there are three different coordination schedules for procurement, installation and design. The master time schedule includes all areas of the project in one document.

The next level below the master and coordinating schedules in the hierarchy are *detailed time schedules* for different areas. Detailed schedules are prepared by the same project team for the areas of design, construction, and installation and commissioning. As the name of the detailed schedule indicates, they are more detailed than the master or coordinating schedules. Each device from the list of equipment is included in that level of schedules.

Subcontractors and sub-suppliers prepare more *detailed work plans*, but these are not added to the detailed schedules which only indicate time frames where the works must be performed. Case Company C checks whether the subcontractors' schedules are feasible and include enough manpower and equipments to complete works in the agreed time.

MS Project is the used software tool used for scheduling. Primavera was used before, but MS Project is widely used by all stakeholders worldwide. Most clients require the use of MS Project and Case Company C also requires it from sub-suppliers and subcontractors. The ability to use and know-how of MS Project is felt to be on a good level in Case Company C because it has been in use for a long time and the users are experienced. The resourcing feature is not used in MS Project because it is felt unpractical for a consulting company to include resource estimates in the schedules. The needed resources have usually already been calculated in the bidding phase and are not estimated any more in the schedules. The frequency of reporting and schedule updates depends much on the project phase. In the project development phase it can be monthly, weekly in the installation phase, and in the commissioning phase even on a daily basis.

Schedules are usually prepared based on similar previous projects. Templates are not used, but old schedules are taken from a project which is most similar to the present one. When the schedule is ready-made it is checked together with all disciplines, project management, the customer and subcontractors for its feasibility. That ensures the commitment of all stakeholders to strive for the best results. In Case Company C the project schedules are examined in the post-project reviews and problems are reported to learn from for future projects. However, despite the pre-implementation and post-project reviews there are no systematic methods of evaluating schedules.

Data of different task durations are collected and stored to back up experts of different disciplines to know exactly how long different activities will take. However, much of scheduling knowledge is gained only by experience and is held as tacit knowledge of each person. Comprehensive conception of the entirety of the plant and the logic of task sequence can be acquired only empirically. Task dependencies are not applied between every task, but all main logical connections are added. Establishing all dependencies in the task chains requires too much work and makes the schedule difficult to interpret. Visible buffers are not used, but in practice the buffers are included in task estimates. Weather conditions are taken into consideration in schedules, e.g., rainy seasons and very cold periods. The overlapping of installation and commissioning phases is usually used as a buffer where commissioning can start earlier although all installations may not be ready.

The scheduler of Case Company C described that a good schedule is realistic, with a clear layout, preferably on one sheet. Physically, the schedule must look like a schedule, showing the right level of detail throughout the schedule. The schedule must be feasible so that everybody can commit to execute it. One of the main weaknesses of schedules is too large and complex structures which make the usage complicated. Some professional schedulers imagine that a good schedule is very detailed and contains all subtleties of scheduling techniques, but on the other hand such schedules become too complex and nobody is willing to use them in daily works.

Experienced schedulers of Case Company C claim that systems and theories for scheduling which are too elegant have been developed. Schedulers feel that methods such as complex networks are far removed from reality. Professional schedulers have left elegant theories in the background and use “seat-of-the-pants” methods to produce simple and feasible schedules.

4.4.4 Case Company D

Case Company D is an energy solutions provider focused on engineering, construction, and procurement projects. It supplies power production facilities, as well as plants providing steam and electricity to process industries and power grids. The case project is a turnkey delivery where Case Company D is designing and supplying industrial boiler island and auxiliary equipment and carrying out the erection and commissioning on EPC basis to Finland.

Case Company D is preparing only one schedule for the entire project, which is divided into three distinct levels. All levels are in one file and different levels can be seen by expanding higher-level tasks to detailed ones. Level 1 is a milestone schedule which is highest in the schedule hierarchy. At level 2, tasks are on system level, and level 3 is called *the main schedule* showing tasks on device level. Level 3 is the most detailed document in schedule format prepared by Primavera.

For each discipline of engineering, procurement, installation, and commissioning is prepared an Excel-based *workplan*. Workplans contain the entire scope defined in the project contract. The workplan includes all detailed tasks of each project discipline and enables progress follow-up at detail level. In practice, the workplan is a tool for disciplines to plan and measure the progress of tasks on a very detailed level. Workplans include description of tasks, performers, budgeted hours, earned hours, planned and actual dates for task milestones. Tasks can be divided up to nine milestones, where to progress can be followed up in detail. The most detailed task in the main schedule can be decomposed into approximately ten more detailed tasks in the workplan. All tasks of workplans are not included in the main schedule because they are too detailed and the main schedule would become too large and complicated. In general, the workplan is used as a tool for planning of tasks. A Primavera based schedule is a visual presentation of workplans, showing sequence and task relationships in schedule format. Excel-based workplans are used because all workers do not have access to Primavera and others do not have enough skills to use Primavera.

In Case Company D a scheduler is responsible for scheduling one entire project. The scheduler's main tasks consist of preparation of schedules, updating, and reporting. The individual scheduler does not prepare the schedule alone but develops it in close cooperation with line managers of different disciplines. Usually, schedulers do not have all the knowledge of different disciplines and can not technically master the entire plant. The scheduler is the expert of scheduling who gathers and coordinates the necessary information of different experts of plant construction. Collecting all necessary data is challenging because the scheduler is not involved in all project-related issues like the project manager. The scheduler needs to enquire and gather up the data from different sources. Sometimes an excessive amount of too detailed and unnecessary information causes extra work.

Case Company D uses Primavera as a scheduling software tool. The scheduler administers the scheduling tool and other project personnel do not have access to the software. The scheduling process starts with filling the workplan templates. The workplans are prepared by line managers and experts of different disciplines. The main schedule in Primavera is constructed based on workplans. The main schedule template is modified to fit each individual project and is adjusted with the information from workplans. Detailed information of different tasks is transferred from workplans to the main schedule. Case Company D indicates time windows for subcontractors and sub-suppliers in which they are going to perform their works. Suppliers and subcontractors provide their own schedules to Case Company D.

Task duration estimates are based on actual durations of previous projects or on expert judgments. Buffers are included in the main schedule, but are hidden in the task durations. Only the project manager and project team members are aware of these buffers.

Dependencies between tasks are added when the main schedule contains all necessary tasks with the right durations. Leads and lags are used to adjust the project into the contractual time frame. All tasks are linked in the schedule and every task has at least one predecessor and one successor.

The main schedule contains resource information and budgeted hours of each task. To enable effective resource allocation, each project and discipline have their own calendars in Primavera. Subcontractors are presumed to work according to Case Company D calendars.

When the schedule is considered to be ready, it passes through many reviews and approvals of the project team, line managers of different disciplines and top management. Assessment of the schedule is done by the project team, but there are no systematic processes or methods for it. Then the approved schedule is baselined.

During the implementation phase, the follow-up and reporting of work progress is done by different disciplines or the site office. They update the workplans and this information is provided to the scheduler, who updates the main schedule.

According to the scheduler of Case Company D, a good schedule includes all important tasks with the right durations and the right timing. Resources are well-allocated and tasks have correctly-budgeted hours. To enable monthly follow-up, the schedule should not be too detailed. The use of both Excel and Primavera is seen as the main problem in scheduling. This is felt laborious because the schedules and workplans are prepared separately and the scheduler has to transfer the data between them.

4.5 Schedules of Case Projects

4.5.1 Quality Criteria combined with Schedule Hierarchy

Detailed quality criteria which were presented in the literature review section in Table 5, are now connected to the schedule hierarchy. Applicability of detailed criteria to different schedule types is assessed with ranking 1 to 3 (1 = weak, 2 = medium, 3 = strong). Assessment is done based on the interview results of case companies. If a criterion has a strong connection to a certain schedule type, then it needs more attention when preparing that type of schedule. All detailed criteria are important in any schedule, but some of them need to be considered more carefully than others. For example, in the target schedule, the tasks are rarely decomposed from WBS work packages while in work plans that happens more often.

Table 7 Characteristics of schedule quality combined with schedule hierarchy

Detailed Criteria	Schedule type			
	Target	Master	Detailed	Work Plans
• Tasks decomposed from WBS work packages	1	2	3	3
• Tasks with explicit names in logical sequence with right dependencies	2	3	3	1
• Duration estimates based on evaluation and previous experiences	1	2	3	3
• Same detail level in each schedule to provide a basis for measurement and control of progress	1	2	3	2
• Provide understandable and usable information to those who use it	3	2	2	2
• Identify critical path as well as critical tasks	1	2	3	1
• Tolerate variation, easily modified and updated	3	2	1	1
• Enhance communication between project stakeholders	3	2	2	2
• Traceability between hierarchy levels	2	2	2	1
• Conform to resource availability	1	2	3	2
• Include buffers which are inserted at the right places	2	2	2	1
	Connection	1=weak	2=medium	3=strong

In the next section, the project schedules that were provided are reviewed, but only the detailed schedules of each project are evaluated more deeply. Most of the criteria have strong connections to detailed schedules, thus these schedules are more interesting to evaluate.

4.5.2 Analysis of Case Project Schedules

Schedules of case projects are analyzed in this section. Schedules received from case companies are from different levels of schedule hierarchy. Three case companies have two schedule levels and one company has four levels. Although case companies title a schedule as a master schedule, it can mean different types for different companies. One of the detailed schedules of each company is examined more deeply. First, the schedule is analyzed with Planalyzer, and then surveyed according to the model presented in the previous section.

Some criteria of the schedule quality characteristics are difficult or even impossible to examine without deeper knowledge of the project's product. Schedules are created by professional project managers, project teams and schedulers with experience of each discipline and process how the product should be built. For a person who is not dedicated to the technology of the concerning project, it is hard to assess certain quality criteria. Also, knowledge of the process of how the schedule itself has been created would be necessary to assess some criteria.

4.5.2.1 Case Project A

Considering the power plant project to Germany, a master schedule which covered all the six plants in one schedule was received for analysis. In addition to this, one installation and commissioning schedule of one individual plant was received.

In Figure 31 part of the master schedule of one plant is shown. It consists of 14 tasks and six milestones. This schedule presents the whole life cycle of one plant with few tasks on one single-page overview. It is mainly intended for communication purposes. Planalyzer is considered to work best for schedules with more than 50 tasks, hence there is no sense in analyzing the master schedule with this software.

There are different colors used for tasks, but the logic of coloring is not clear and the same colors are not used in more detailed schedules. Predecessor relations of tasks are well in place, but too much start-to-start and even start-to-finish relations are used. The structure of the schedule is logical and very simple and, as can be seen, it is easy to check that everything is in the right place. In this way, it might work well for the purpose of communicating the schedule to different stakeholders of the project.

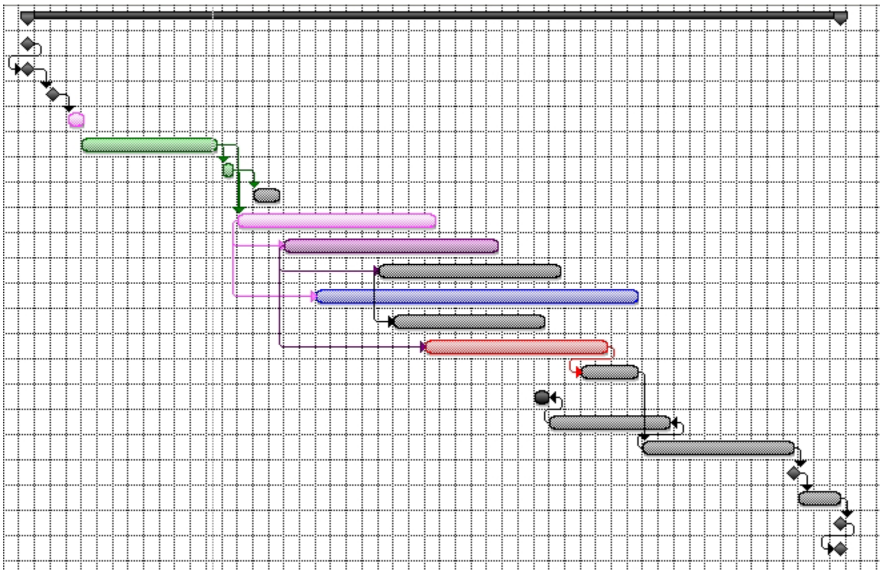


Figure 31 Master schedule of one plant

Figure 32 presents part of the installation and commissioning schedule of one plant. At the moment of the interview that schedule was not completely ready because negotiations with subcontractors were still going on. The schedule would be updated all the time until the contracts would be ready with subcontractors and they would provide schedules to Case Company A.

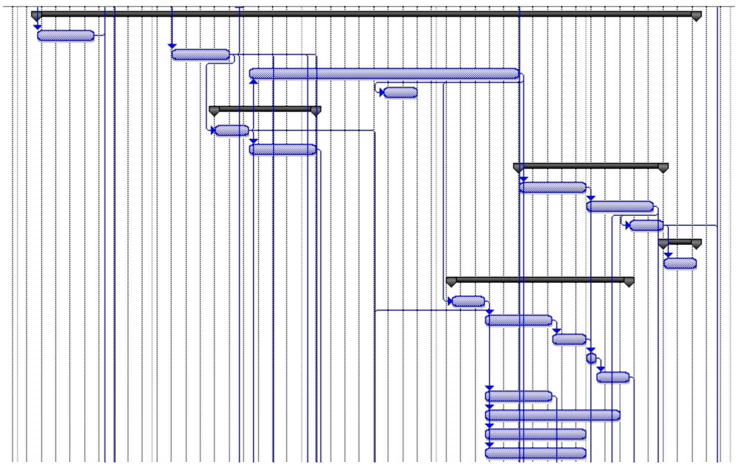


Figure 32 Part of the installation and commissioning schedule

The installation and commissioning schedule contains three milestones, 33 summary tasks, and 182 tasks. All main summary tasks of that schedule are exactly the same as in the master schedule. That facilitates traceability and comparison of schedules of different level.

When the schedule is analyzed with Planalyzer, file check gives results which are presented in Figure 33 which is also the general output view of the file check. The number of orphan tasks is 71, which is a large number if the schedule contains totally 182 tasks. This is a consequence of task dependencies and Planalyzer considers a task without a successor as an orphan task. From Figure 32 it can be seen that some tasks are at the end of the activity chain and the last task is not linked anywhere, which also presents as an error in Planalyzer. Although every task has a predecessor (or many of them), those which are reported as errors in Planalyzer are without a successor.

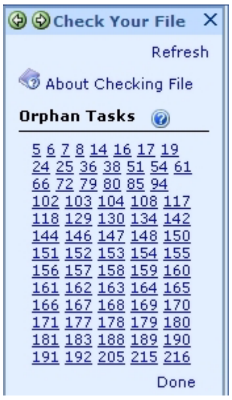


Figure 33 File Check of the installation and commissioning schedule

Planalyzer analysis gives the results as presented in Figure 34 which is the common analysis output view. All risk climate factors are kept on the default value of 3. There are 71% task assignment errors in the schedule, which means that the results are not reliable. Although the probability for the last milestone is 22%, it can not be believable if 71% of tasks are left outside the analysis. A prerequisite for the analysis is that all the task assignment errors are corrected and then the analysis can be done again. The schedule was not modified to fit for Planalyzer analysis due to the limited time for project team of Case Company C.

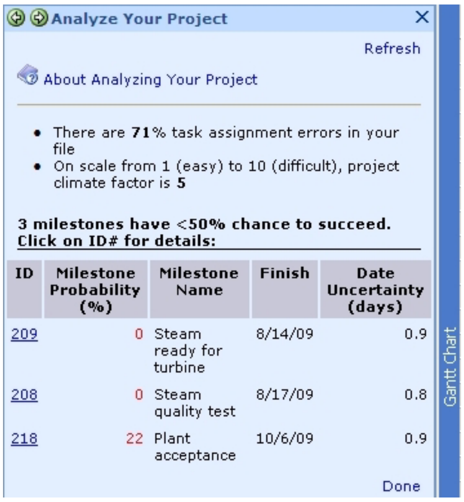


Figure 34 Planalyzer results

The schedule can be reviewed without Planalyzer according to the quality criteria presented. Task names seem to be explicit and understandable in most parts. Some sections include identical task names, but that should not be a problem because they are under different summary tasks. Tasks are sequenced in logical order which follows the building process in chronological order (foundations, installations, instrumentation, and commissioning). Some parts of the schedule were not yet ready and subcontractors' parts were not indicated in detail in the schedule. Therefore, some task durations are too long (e.g. 90 days). Parts which were ready are on the right detail level and can be used for progress follow-up purposes. The critical path can be also identified because task dependencies are indicated. The problem with the critical path is that many tasks lack successor connections which might lead to faulty paths. Many tasks have start-to-start dependency connections.

Overall, the schedule seems to be well-structured and easily understood. With some corrections it would work well when it is ready and could be analyzed also with Planalyzer. At the moment, some tasks are too long and lack successor connections which affects the understandability, but that is due to missing information from external actors.

4.5.2.2 Case Project B

From Case Company B was received materials for the analysis of project schedules of substation delivery to Zambia. In the analysis one master schedule of one substation will be analyzed. Detailed schedules for site works were prepared during the site phase but were not provided for the analysis. The master schedule which was ready when the implementation started will be analyzed in this section.

The master schedule contains two milestones, seven summary tasks and 56 tasks grouped into engineering, manufacturing and shipment, civil works, installation works, and testing and commissioning.

Planalyzer is aimed at analyzing schedules which contain more than 50 tasks, so the evaluation of this master schedule is not necessarily useful. However, Planalyzer gives 13 orphan tasks and two empty milestones in the file check. The schedule can not be analyzed because none of the milestones are linked to the tasks (Planalyzer gives an error message). If the last milestone is connected to the last task, then analysis gives the results of 54% task assignment errors, which is not reliable enough for further review. All risk climate factors were kept on default value 3 so that results are comparable to other analyses.

The problems of schedule for Planalyzer analysis were informed to Case Company B representatives and after the interview a corrected version of the schedule was received. Necessary successor connections between tasks were added. The total duration of project was enlarged by a couple of days. Planalyzer analysis gave 0% task assignment errors, which means that the structure of the schedule is suitable for evaluation. When task assignment errors are 0% all tasks are taken into account in the analysis. Although there are no errors in the schedule, the milestone probability of the last milestone (commissioning) is 0% for the assigned date.

The following three figures are general outputs of Planalyzer analysis, where more detailed descriptions of the results can be seen. Time-dependent milestone probability is shown in Figure 35. It can be seen that the milestone probability of success is increasing from the date 17.10.2008 and reaching 80% on 28.11.2008. This means that six weeks later, the change to complete the project on time is 80%.

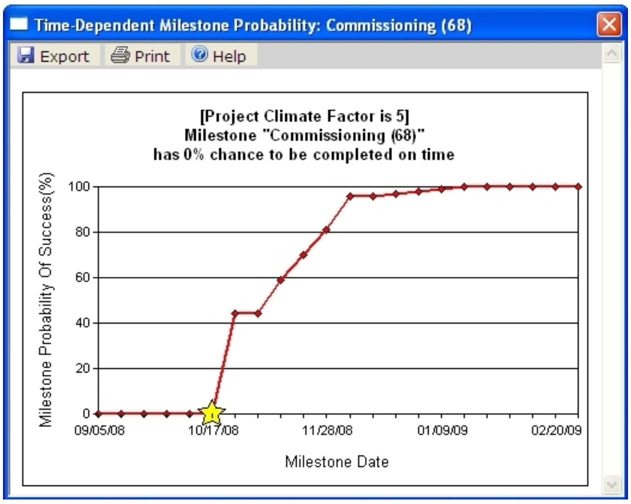


Figure 35 Planalyzer results, Time-Dependent Milestone Probability

If the milestone probability is low it can be enhanced by introducing time gaps, extending milestone dates, reducing the number of dependencies, or re-planning to do some tasks in parallel.

In Figure 36 it can be seen that for average task slip of 9.4 days, the last milestone has 0% change to be completed on time. When the average task delay decreases to two days, the milestone probability of success increases to over 80%. A well-designed task chain is considered robust if the milestone can tolerate reasonably large average delays.

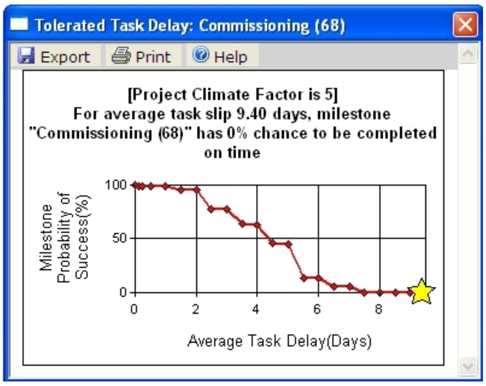


Figure 36 Planalyzer results, Tolerated Task Delay

Figure 37 presents the priority of tasks. The chart shows the ratio of task impact to average task impact on milestone probability of success. Tasks with high impact affect milestone probability the most. These tasks should be revised carefully to see if the impact can be diminished.

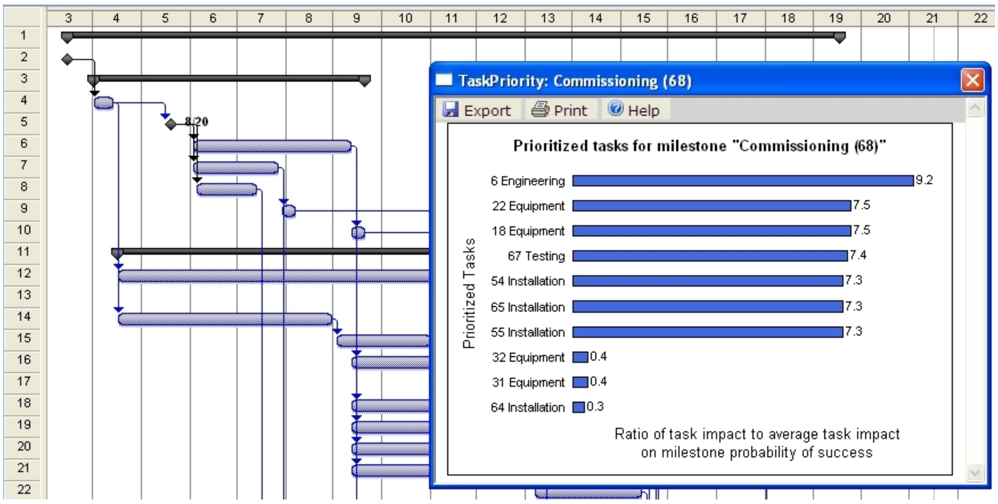


Figure 37 Planalyzer results, Task Priority

Figure 37 was the most interesting to Case Company B representatives because they knew the tasks which were shown in the chart, and thus could evaluate how well Planalyzer results correlated to the real project. Tasks shown in the chart seem to have a high impact on the last milestone and when analyzing in more detailed it can be found that task number 6 has 13 successors and task number 22 has 4 predecessors. That can partly explain high impacts, but when looking at the links of tasks it can be seen that all tasks with high impact in the chart are linked with each other from task 6 to task 65. That indicates clearly that tasks in long task chains with many dependencies have high impact on milestone probability.

In Figure 38 part of the identified critical path (in red) of the schedule is shown. It can be seen that all the tasks listed with high impact in Figure 37 are on the critical path. The result is interesting when comparing with Planalyzer results. If Planalyzer can indicate prioritized tasks based on a wave model without using critical path calculations, the method would be useful and practical. On the other hand, the new information that Planalyzer is providing is to be seen because important tasks can be indicated with CPM and the critical path must be monitored and controlled with extra care anyway.

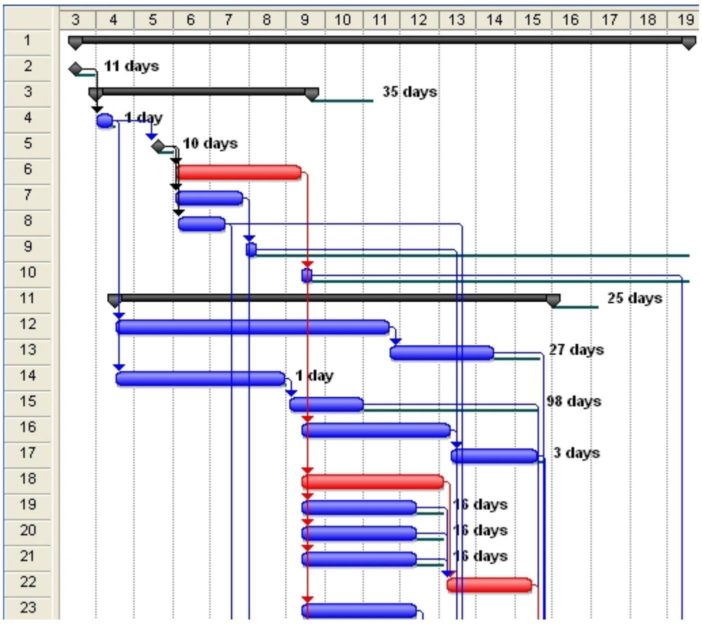


Figure 38 Part of the critical path

When analyzing the schedule without Planalyzer it can be noted that the overall structure of the schedule is clear. Most probably, that is a consequence of few tasks (totally 56) in the same schedule. The tasks are not on a very detailed level, thus the structure seems to be simple. That can be noticed from task durations, which vary from 3 days to 157. Most tasks are over 50 days whereas some are only 3 days which is too large a scale in the same schedule.

Task names are explicit and sequenced in logical order. Tasks are grouped under understandable summary tasks. Links between tasks are mostly in place and only finish-to-start relationships are in use. Intermediate milestones are totally missing, and only one milestone at the start and one at the end of the project are indicated.

This schedule gives a good overall view of the project, but is not suitable for detailed control of project progress. For different areas there should be more detailed schedules to enable control and measurement of works.

4.5.2.3 Case Project C

Case project C considers a supply of paper mill to Poland. Materials received included one target time schedule, two area time schedules, and two detailed time schedules. Two of the first-mentioned schedules will be presented briefly and one detailed installation schedule will be analyzed in more detail. The received schedules are mainly for the site construction phase, thus there are no coordinating schedules (for procurement and engineering,) included in this analysis. In addition to the above-mentioned schedules, the material contained one detailed schedule of a civil subcontractor. It was not analyzed because it was not created by Case Company C.

The target time schedule is the highest-level schedule in the schedule hierarchy of Case Company C. This schedule comprises the entire project on a single page. The schedule includes the main milestones and main tasks of engineering and construction. Six main areas of mill construction are presented with three subtasks and one milestone each.

The structure of the schedule is very clear. Each task type (construction, installation, commissioning, etc.) have individual colors of task bars. Totally the target time schedule includes 59 items and all fit in one page, which makes it visually easy to understand and communicate. Part of the target schedule is shown in Figure 39. Task names are descriptive and the sequence of tasks is logical. Dependencies of tasks are not indicated on the document (PDF - Portable Document Format), but there is no need for that because the structure is self-evident.

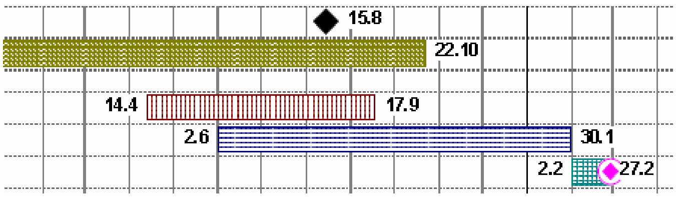


Figure 39 Part of the target time schedule

Next in the schedule hierarchy are area time schedules (also called master time schedules), where the main areas of the target schedule are presented in more detail. Each of these schedules indicates engineering, procurement, and construction works of one area. This schedule presents all tasks in one page, and the received example schedules contain 29 and 36 items. In the area time schedule the same colors as in the target time schedule are used, which is logical and facilitates readability. The structure is also the same as in the target time schedule, it is clear and logical, and predecessor connections are not shown.

The next step to more detailed schedules is detailed time schedules. One of the detailed installation time schedules received will be reviewed. These schedules contain enough tasks for Planalyzer analysis. Analysis is begun with Planalyzer evaluation and then according to quality criteria.

The schedule contains a considerable number of tasks. There are 18 top-level summary tasks which include 105 summary tasks under them. Totally, the schedule contains 1173 tasks and 161 milestones.

When the schedule is analyzed with Planalyzer, the results are as follows. File check gives 616 orphan tasks, 99 empty milestones, and 31 mis-assigned tasks (task finishing after milestones). Project analysis indicates 91% task assignment errors, which means that the results are not at all reliable. The lack of predecessor relationship connections is the main reason for the significant number of errors. Although some tasks have almost 50 successor tasks, it is not acceptable if some tasks are not connected to any other tasks.

Although Planalyzer results were not reliable, the schedule can be assessed by using criteria from the evaluation framework. When comparing the area time schedule and detailed time schedule, it can be noted that they do not fully matching each other and do not enable traceability. The schedule contains much other information regarding tasks. There is a position number, line and level for each task indicating the physical location of tasks in technical drawings. Suppliers and contractors for performed tasks are also mentioned. Different tasks can be marked with flags which affect the color of the task bar. There are different colors for different activities (civil works, installation, tanks, instrumentation, electrification, etc.). Part of the schedule is shown in Figure 40.

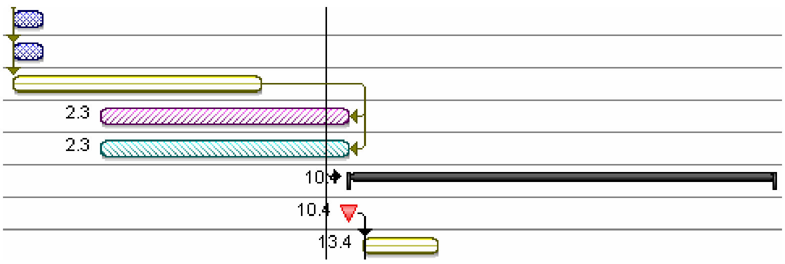


Figure 40 Part of the detailed installation time schedule

All task names are not explicit because some names include only numbers or codes and in some parts there are many tasks with identical names. The difference can be found only from different position numbers. Task durations are mostly less than 20 days, but there are also dozens of task durations up to almost a hundred days. These tasks need to be broken down into more detailed sub-tasks.

Task dependencies are defined in about half of the tasks, and therefore, the critical path can not be identified when the connections are missing. There are also some tasks with finish-to-start connections which should not be used at all. These links are mostly backward connections from tasks to milestones.

Overall, the schedule is detailed enough for control purposes, but there is always a coordination problem with thousands of tasks. The use of different taskbar colors is valid in this kind of schedule with many tasks to facilitate the readability and understandability. Resourcing is not included in the schedule, but the supplier and contractor of each task is indicated. Assigning all resources to thousands of tasks performed by different contractors would be extremely laborious or even impossible. These detailed schedules of Case Company C contain a lot of information compared to other schedules presented earlier in this study.

Other criteria for schedule evaluation listed in the framework are difficult to assess without deeper knowledge of the project's product and the processes of how it should be built.

In addition to schedules of Case Company C, one detailed schedule (or work plan) was received which was provided to Case Company C by a civil subcontractor. The schedule itself describes earthworks and foundation construction, but the name of the schedule is very interesting. "Harmonogram" refers strongly to Adamiecki's Harmonygraph which was presented very early in this study. Adamiecki was Polish, the subcontractor is from Poland and, that might be the reason why they are still using the same term for the schedule which was developed in 1896.

4.5.2.4 Case Project D

The schedules of Case Company D are prepared in Primavera and Excel and can not be analyzed with Planalyzer because it is only MS Project-compatible. Printouts of Primavera schedules (in PDF) only indicate task names and their starting and finishing dates. Based on that information is not possible to analyze the schedules in much detail. Primavera is not used in this study, thus, any additional information of schedules of Case Company D can not be seen.

There is only one main schedule which is created in Primavera and workplans which are prepared in Excel. The main schedule is divided into three levels which can be seen by expanding summary tasks into more detailed ones. The level 1 schedule only indicates tasks like major milestones, document delivery, payments, engineering, design, procurement, erection, commissioning, and training. When all summary tasks are expanded, the level 3 schedule is found to contain totally almost 2600 items, which include 380 summary tasks, almost 1500 milestones, and a little over 700 tasks. The number of milestones is extensive because each procurement item contains nine milestones. Part of the level 3 schedule is shown in Figure 41.

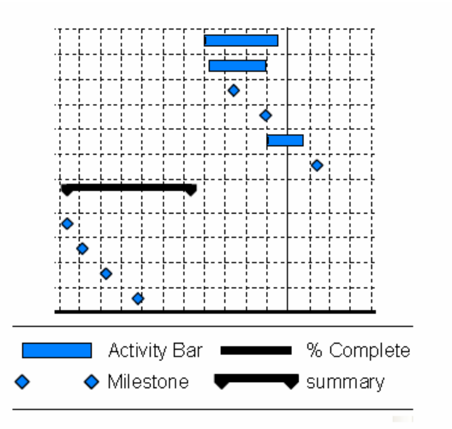


Figure 41 Part of Level 3 Schedule

Task names are clear and understandable and tasks are grouped into logical entities. The schedule indicates a logical sequence of works throughout. Task durations vary too much, especially in the erection part. Below one summary task can be task durations varying from one day to 100 days. These tasks are possibly broken down into more detailed tasks in Excel-based workplans.

As presented before, workplans are used for planning, controlling, and monitoring the most detailed tasks. Progress of detailed tasks can be measured with workplans and then the information is transferred to the Primavera-based main schedule. Workplans include roles, budgeted hours, and milestone dates from where earned, planned, and forecasted hours of different tasks can be calculated. A workplan does not indicate the sequence of tasks and their dependencies. Workplans of different areas contain several thousands of tasks.

The use of two different programs for scheduling seems to cause extra work in Case Company C. All the same information which is indicated in workplans should be possible to present directly in the Primavera-based main schedule. The main schedule can be broken down into smaller entities if it becomes too large to handle.

As I have understood, the Excel-based workplans have been in use for a longer time than Primavera in Case Company C, so employees use workplans in project planning extensively. The use of two different programs should be changed to only one scheduling tool. That may need more Primavera training to employees, but it can increase interest and motivation towards scheduling in general.

4.6 Cross-Case Analysis

Case projects presented in the previous section are compared below. In Table 8 basic information of each project is first provided, followed by schedule-based data. Then the analyzed schedules are compared and implications of the interviews are taken into account.

Table 8 Comparison of case projects

	Case Company			
Project Information	**A**	**B**	**C**	**D**
Project type	EPC	EPC	semi-EPCM (mere equipment supply by main contractor)	EPC
Product	Power plant	Substation	Paper mill	Boiler island (power plant)
Destination country	Germany	Zambia	Poland	Finland
Supply time	78 weeks	80 weeks	104 weeks	146 weeks
Contract signing date	11.4.2007, contractual time started to run not until customer was ready with all permits.	15.6.2007	July 2007	27.4.2007
Project completion according to contract	23.3.2010	15.11.2008	30.6.2009	12.2.2010
Now completed (%)	Engineering & procurement 100%, Construction & commissioning 43%	98 %	75%	82 %
Project behind / ahead of schedule	Ahead 30 weeks	Behind 12 weeks	Behind 9 weeks	No delays
Main reason for the delay/earliness?	Due to customer delay the detail engineering could be finished and main equipment could be manufactured before contractual time started to expire.	Problems in civil works, customer made changes	Late purchasing and problems in civil works contract (work methods)	-

Delays schedule dependent or caused by schedule	No	No	Partly due to unrealistic civil works schedule	-
Estimated completion date	23.8.2009	15.4.2009	30.9.2009	12.2.2010
Used scheduling software	Microsoft Project	Microsoft Project	Microsoft Project	Primavera 5.0 SP4 and Microsoft Excel
Main responsible of scheduling	Project Manager	Project Manager	Scheduler	Scheduler
Number of hierarchy levels	2	2	4	2
Different schedule types	Upper level is a rough master schedule for six plants. Installation and commissioning schedule for each plant	Master schedule and detailed schedule of each substation	Target, Area, Master and Detailed schedules	Master schedule in Primavera and detailed workplans in Excel
Resources included in schedules	No	No	No	Yes
Visible buffers in schedules	Contractually remarkable buffer. In schedule, tasks are not including buffers, but they are intentionally made "realistic".	No	No	No, but floats included into tasks
	A	**B**	**C**	**D**

All of the case projects studied in the empirical part are EPC-type delivery projects. The delivery time of case project A is almost half of the time compared to project D. Although it is complicated to compare the size of the projects, it can be concluded based on the scope and delivery time that case projects A and B are smaller than C and D. Complexity of the projects is also difficult to assess because, for example, the destination country of project A is very different from those of projects B and D. Regardless, all the projects are engineering-type projects where the methods and goals are well-defined. All the companies have been supplying many similar end products, and processes for project execution should be well-known. These projects can not be compared to the first-of-a-kind projects, i.e. those which have never been done before.

The different sizes of the projects can also be noted from the approaches of the case companies for the question as to who is doing the scheduling. Case companies C and D are employing responsible schedulers for each project who only prepare schedules and update them. In case companies A and B, the project manager establishes schedules with the project team together with all other works. Case companies using professional schedulers face the same problems that Laufer and Tucker (1987 and 1988) as well as Winch and Kelsey (2005) presented in their study. Schedulers specialized in scheduling lack construction experience and they feel information gathering to be troublesome. Project managers do not have the quality time to perform scheduling, but they have good practical knowledge. Among schedulers this is the reverse.

In all companies, the schedules for the case projects were taken from some similar previous project and modified to fit the current one. None of the case companies performed systematic evaluation of schedules before implementation or after project completion. They felt it was difficult to accomplish because the results did not depend only on the quality of scheduling, as was indicated by Laufer and Tucker (1987).

Schedules prepared by professional schedulers in case companies C and D are more extensive than in case companies A and B. It can be seen clearly that case companies C and D are putting more emphasis on schedule development. Schedules of case projects C and D and workplans of D contain several thousands of tasks whereas schedules of projects A and B include only several hundreds. This difference can explain why case companies C and D are using full-time schedulers. Preparation and updating of large schedules needs more concentration and time than a project manager can devote to them. On the other hand, if schedules are created by a professional scheduler, there is a risk that schedules become too large and difficult to understand for normal employees. Schedules can be too complicated to find essential information.

The programs used for scheduling seem to be in line with the studies mentioned in the literature (Pollack-Johnson and Liberatore 1998 and 2003; Raymond and Bergeron, 2008). Three out of four companies used Microsoft Project and only one used Primavera. Case Company C had been using Primavera before, but changed to MS Project because most of its stakeholders are using it. This is also compatible with the size of the projects because it is widely recognized that Primavera is mostly used for large and complex projects.

Resourcing is only utilized in Case Company D because Primavera is considered to be better suited for that purpose. In other case companies, resourcing was seen to be too complicated when dealing with several subcontractors and sub-suppliers and using MS Project. On the other hand, the use of MS Project is perceived to be easy while Primavera needs more training and experience. In Case Company D the scheduler is the only one using Primavera and the other employees are using Excel. This burdens the scheduler unnecessarily who has to do twice the work in many phases of the scheduling process. The advantage of MS Project is its wide use among the project team and stakeholders. Many employees can create and edit schedules, while it can negatively affect the quality of schedules, as argued by Cornish (2008).

All other case companies except C are using two levels of schedule hierarchy. This appears to work well in case companies A and B where schedules are not containing thousands of tasks. Instead, in Case Company D where the main schedule is containing far more tasks than the schedules of A and B, it can become difficult to read and understand. If a project is large and needs a large number of tasks to indicate all the necessary work it would be better to split schedules into smaller entities as in Case Company C. Various authors (Nicholas, 2004; Clough et al., 2000 and Alsakini et al. 2004) have described similar schedule hierarchy models which are used in case companies. Schedules at a certain level of detail can be expanded to more detail when the implementation comes closer.

Case companies are performing scheduling in different horizons as Laufer and Tucker (1988) and Alsakini et al. (2004) have defined. First, long-term schedules with less detail are prepared for the top management in home offices while short-term detailed schedules are created later for on site execution.

Three out of four case projects were late or ahead of schedule, but none of these that were delayed or early were direct consequences of or depending on scheduling. It seemed to be a general opinion in all case companies that schedules are one of the most important tools for project management, but usually they do not cause delays of a project. There are various other variables which affect a project, and a schedule can not influence them.

It can be concluded that among case companies the scheduling is on the most advanced level in Case Company C. As was presented before, they have clear documentation and instructions for time management. The coordination of project scheduling functions seemed to provide efficient processes for managing projects. Although the scheduling is performed well in Case Company C, it is not assured that the projects will be completed on time, as can be seen from the particular case project C which is late.

In the following, the analyzed case schedules are compared with each other, and the criteria are shown in Table 9.

Table 9 Comparison of analyzed schedules

	Case Company			
Analyzed Schedule	**A**	**B**	**C**	**D**
Name	Installation and commissioning schedule	Master schedule	Detailed installation time schedule	Main schedule, level 3
Position in the schedule hierarchy	Most detailed	Second most detailed, site schedules are more detailed	Most detailed	Second most detailed, workplans are indicating more detailed tasks
Used software	Microsoft Project	Microsoft Project	Microsoft Project	Primavera
Number of milestones	3	2	161	~1500
Number of summary tasks	33	7	123	~380
Number of tasks	182	56	1173	~700
Task definitions	Same names in different sections, but mainly explicit	Explicit	Some same names in same sections, only different position numbers. Some number codes, but mainly explicit	Same names in different sections, but mainly explicit
Logical task sequence	Yes	Yes	Yes	Yes
Different colors for task bars	No	No	Many	No
Dependency connections	Mainly finish-to-start, but also start-to-start	Only finish-to-start	Mainly finish-to-start, but also start-to-start, finish-to-finish and even finish-to-start	-
Range of task durations	1 - 90 days	3 - 157 days	1 - 97 days	1 - 745 days
Subcontractors' parts added / included	Partly	No	No	No
Allows control	Yes	Not detailed enough	Yes	Some parts yes, but some parts need backup data from workplans
Critical path identified	Yes	Yes	No, but generally known	Yes
	A	**B**	**C**	**D**

It is difficult to compare schedules of case projects A and C with B and D because B and D are not the most detailed schedules prepared in the case companies. The main schedule of Case Company D can be shown to correspond to the detailed schedules of case projects A and C, although it is not on the same level of detail and it incorporates all project activities in the same schedule.

Many criteria presented in the framework of schedule quality criteria are impossible to assess without extensive knowledge and understanding of the specific project, thus, analysis is based on quite generic and superficial assessment of schedule structure and appearance.

Only Case Company A is including subcontractors' parts in the schedule. Other case schedules only indicate time frames or rough task estimates where subcontractors perform their works. This is similar to the model presented by Alsakini et al. (2004) where the main contractor indicates the general timing for the overall project and subcontractors develop and provide details of their activities. The schedules provided can be linked into a summary schedule which can be divided into sub-networks. If subcontractors provide schedules in the right format, it is simple to attach them to the schedules of the case company. In all case schedules it can be seen that there are some tasks which are indicating time frames for larger parts which should be broken down into more detailed tasks. That is indicated by the large range of tasks durations. Tasks lasting over 10% of total project duration should be split into more detailed ones. In case schedule D many task durations are over 500 days, which is absolutely too much, but supposedly they are divided into more detailed portions in workplans. However, almost all schedules except case schedule B are suitable for control and measurement purposes. Identification of the critical path can somehow be problematic in case schedules C and D due to the extensive number of tasks.

It was realized that the schedules and scheduling are on a better level in case companies C and D than in A and B. Schedulers from both companies C and D stated that the attitude toward schedules were on a satisfactory level. Project managers of case companies A and B claimed instead that their schedules needed enhancement. Obviously, case companies C and D who employed professional schedulers provided better-quality schedules. On the other hand, the schedules of case companies C and D are more complicated and possibly difficult to understand for individuals who are not dedicated to the schedules.

Overall, it can be concluded that the schedules of Case Company C are on the best level of this group, but Case Companies B and D could not be considered fully in the evaluation because of a lack of the right level of schedules in the correct format. Schedules of Case Company A are not very advanced but are understandable and would work well in their purpose because there is always the dilemma of schedules which are too detailed. It would have been interesting to evaluate large schedules of case companies with Planalyzer to get an impartial and structural assessment, but it was not possible because of the many errors indicated in the schedules by the software.

4.7 Managerial Implications

In this section suggestions for schedule evaluation are presented. These frameworks are based on the ones presented earlier in the synthesis part of the literature study. Both models presented are modified according to the results of interviews and schedule analysis. The suggested checklist and criteria for evaluating schedule quality can be used as a managerial tool as well as an organizational model to create better quality schedules.

4.7.1 Suggested Evaluation Checklist

After the interviews of case company representatives and case schedule analysis a need for a different method to evaluate project schedules was realized. The prerequisites for Planalyzer seemed to be too high for the case project schedules. Lack of successors was the main cause of errors, so the results were not as reliable or useful as had been expected. In the interviews the case company representatives brought out their concern about the quality of their schedules and the lack of tools to evaluate them. Based on these problems a checklist was formulated that could be browsed before compilation of the schedule as a reminder of the requirements of a good schedule. The main purpose of this list is to check the ready-made schedule and to assess its feasibility for implementation. The checklist is presented in Appendix D.

If the project schedule is reviewed without a plan, it is often performed by looking at everything, which leads to poor results. The evaluation should be organized and planned to cover most of the known issues systematically. The checklist is divided into eight areas which follow the scheduling process in PMBOK. The questions it contains try to ensure that a schedule includes all necessary components and processes are conducted in the best way possible. It also works as a reminder of the activities that should be included in the process and it can be viewed before the scheduling has started. Reviewing of the checklist would be useful even earlier in the project development phase to get ideas for defining the scope and WBS because these elements also substantially affect the schedule quality. The checklist may need to be used often during the planning phase to ensure that all needed aspects are considered. Many tasks or even entire parts of the schedule are received from other departments and subcontractors and they need to be revised carefully before combining them with the main schedule. This can be facilitated by providing the same checklist to be used in their scheduling processes as well.

The checklist is mainly aimed at detailed schedules, but can be applied to other schedule types too if some items are modified or left out. The results from the checklist give an indication of the quality of a schedule. Many "No" answers signify that schedule quality is not on an adequate level. Items with "No" answers should be revised and corrected if possible. All the questions are not applicable to every project schedule, but most of them should be included in the review to get a comprehensive view of the schedule. In the comments field additional information of the question can be given.

4.7.2 Suggested Criteria for Evaluating Schedule Quality

The framework presented earlier for the quality criteria of a schedule is modified based on case company interviews and case project schedule analysis. This framework can be used to develop schedules with better quality and also to assess the quality of developed schedules. If the framework is used from the very beginning of schedule development and all the needed prerequisites for Planalyzer are fulfilled, the ready-made schedule can be analyzed with the software tool. That makes the structural assessment of large and complex schedules possible because otherwise it is almost impossible without any computerized tools.

The criteria in Table 10 are described compactly and specified and described in more detail later.

Table 10 Modified criteria for schedule quality

Higher-level Criteria	Detailed Criteria
• Realistic • Feasible • Simple • Make commitment • Accurate • Timely	1. Decomposed from WBS 2. Explicit descriptions 3. Logical sequence 4. Indicate predecessor relations 5. Well-evaluated estimates 6. Sufficiently detailed for measurement and control 7. Standardized 8. Highlight critical tasks 9. Flexible, modifiable, and updateable 10. Communicative 11. Resourced 12. Buffered

Higher-level criteria are hard to define and generally can be assessed via detailed criteria. It is difficult to assess directly how realistic a schedule is, but if detailed criteria from 1 to 12 are well-fulfilled, the schedule has a high probability of being realistic.

1. Decomposed from WBS

It is important that the schedule contains all the necessary work to be performed in the project. A work breakdown structure provides a logical and hierarchical structure of the project's scope of works. The project schedule should be developed around the WBS and it should be directly relatable to the WBS. At the lowest level of the WBS there are defined work packages which can be scheduled. Tasks should be decomposed from the work packages of the WBS.

2. Explicit descriptions

Different tasks in the schedule should have names that are unique and clear. Explicit names should describe what is included and not included in the task. Confusion of tasks with duplicate descriptions can be avoided by indicating different areas in the beginning of the name (Area C – task description).

3. Logical sequence

Task sequencing involves identifying a logical order of work performed in the project. The sequence of the tasks should be in line with normal construction practices. It is important to understand the priorities and planned work sequence among subcontractors and sub-suppliers as well. Tasks can be sequenced so that they define logical groups, which may make it easier to find the desired schedule information. The project team, subcontractors and other key stakeholders should be taken into account during the sequencing and scheduling of processes in the early stages of the project because they are in the best position to know their work.

4. Indicate predecessor relations

Identifying the predecessor relationships between tasks requires knowledge of the sequence and dependencies of the tasks. Using four different scheduling dependency types (finish-to-start, start-to-finish, finish-to-finish, and start-to-finish) to connect tasks with logical relationships provides a network diagram. It is unusual to use start-to-finish relationships in a schedule and it should be confirmed that they are used intentionally. Some dependencies can be discretionary and can be sequenced based on best practices. Leads and lags can be applied to define the logical relationships accurately. Each task should have at least one predecessor and one successor. The number of dependencies between tasks should usually be double the total number of tasks. However, too many dependencies negatively affects the probability of a task chain ending in a milestone.

5. Well-evaluated estimates

Task duration estimates should match the quantities of work involved and required resource type. Historical information from tasks performed in similar previous projects is a reliable source of data. Expert judgments including consultants, professional associations, the project team, stakeholders and other organizational units can provide specialized knowledge of the durations. Subcontractors' participation in the duration estimation of their tasks ensures the most accurate information. It should be noted that when a project is evolving, more precise data are available, and the accuracy of the duration estimates should improve progressively.

Weather conditions should be examined in case of cold winters and rainy or hot seasons. These periods can significantly affect productivity levels. In addition, the destination country can also have an important influence on the project especially when considering developing countries. In any schedule level, the contingency reserves should not be included in task estimates.

6. Sufficiently detailed for measurement and control

The right level of detail in each schedule can be achieved by organizing schedules in hierarchy levels. The same level of detail in each schedule ensures better monitoring and control of tasks during the different phases of the project. Different hierarchical levels of schedules must be related to each other to enable traceability. This can be achieved by keeping the same milestones on all schedules from target schedules to work plans. A schedule at a particular level of detail must be expanded to more detail when the execution of the work comes closer. Monitoring and updating of the detailed schedules (work plans) are performed first and then aggregated and summarized upwards to the higher-level schedules. If site personnel develop daily schedules or work plans they must be consistent with higher-level schedules, otherwise it may indicate problems with the overall schedule.

Too little detail makes the project control difficult because necessary information is not readily available. Long tasks, especially just before milestones hamper the control of reaching target dates. And too much detail creates too large of a schedule which is laborious to interpret and manage. The level of detail is considered to be adequate when a person viewing the schedule is aware of the tasks without having to rely on other information.

7. Standardized

Schedules should be standardized to satisfy the various needs of schedule information required at each level of the organization during different phases of the project. The top management is not interested in the most detailed tasks, while they are invaluable for the site personnel. One way to ensure the understandability of schedules is to define standards for them. All schedules should look like a standard schedule, regardless of the project’s type or size. Standardized schedules accustom employees to a customary model which is easy to understand and in which necessary information can be found readily. The utilization rate of schedules will be improved when employees are familiar with them.

The lessons learned regarding scheduling should be captured more efficiently to enhance the quality from one project to another. Good practices should be developed to standard methods and the same problems recurring from project to project should be avoided.

8. Highlight critical tasks

The first suggested critical path should be reviewed carefully to see if it is feasible. The correct critical path will indicate critical tasks which will help the project team to prioritize works. In case of delays, critical tasks are the most important to focus on in order to reduce additional delays. Usually, about 10% of tasks should be critical or near-critical. A schedule with too many critical tasks or many critical paths indicates a tight schedule. Near-critical tasks have very little float and can become critical when delays occur in the project. These tasks should also be examined carefully. A project network with many tasks without predecessors or successors will result in an incorrect critical path and unrealistically high floats.

9. Flexible, modifiable, and updateable

Schedule flexibility is determined by the amount of total float. Adjustments to task durations, logical relationships, and leads and lags can affect the amount of float. Once the schedule is created, it must be reviewed and revised regularly during the project life cycle. If the updates and modifications are simple to perform, the chance that they are realized is higher. Standard settings of schedules offer a balance between accuracy and maintainability. Subcontractors and sub-suppliers should be used if possible to update the schedule, since they are usually closest to the actual work.

10. Communicative

The schedule should be easily and clearly communicated to all project participants and stakeholders. The schedule provides a mechanism for the project team to consistently communicate project-related information between different stakeholders. A high-quality schedule is an effective tool to transfer and exchange information among project stakeholders. Project schedules can be used as an agenda in project meetings to review important issues. Distribution of updated and revised schedules to stakeholders can be done timely in an electronic format.

When using the schedule, it should be visibly presented in the project office or in the site facilities. A large copy attracts more attention, is readable and easily communicated to employees and stakeholders. Changes and updates can be written directly on the paper copy and it can be referred to rapidly and regularly.

11. Resourced

Resources are often the real limiting factor and determine the timing of tasks and the critical path. Although most schedules do not include resourcing, the amount of equipment, manpower, and crew sizes should be carefully assessed as well as when each resource will be available. Too many tasks scheduled at the same time are usually not achievable. Identification of the quantities and types of resources required for each scheduled task should be included in the scheduling process even though they are not incorporated in the schedule. A separate resource calendar can be used to facilitate resourcing.

12. Buffered

Buffers included in task estimates can make the schedule even worse than without them. Buffers are often added to manage uncertainty, but adding hidden buffers to task estimates can make things complicated. Adding more buffers never seems to be enough. The unintended side effects of this padding increase the likelihood of problems because of two human behaviors known as Parkinson's Law (work expands to fill the available time instead of finishing early) and student syndrome (tendency to start working as late as possible). These effects can be avoided if the buffers are visible and inserted at the right places. According to the critical chain method, the buffers should be placed in the end of the project as a project buffer whose consumption can be monitored to evaluate the progress of the project.

5 Conclusions and Discussion

The objectives of this study were to get an understanding of project scheduling processes and to find methods and tools to assess the quality of project schedules. To be able to perform the evaluation of schedules a framework for quality criteria based on studied literature was formulated. The framework was further developed based on case company interviews and analysis of case schedules. One new and promising software intended for schedule analysis was also introduced and utilized in the evaluation. Based on the results, managerial implications which could be used for developing standardized, structured schedules and evaluating them regularly were suggested.

Current project management literature and studies define realistic schedules as a critical success factor of projects. There is extensive literature regarding project management and scheduling. However, studies concentrating on schedule evaluation are scarce or non-existent. It has been indicated in previous surveys that the gap between project scheduling theory and project management practices is still wide, and it was indeed perceived also in this study. Scheduling theory and different methods for schedule development have not been diffused into everyday practices of project scheduling.

Many factors and environmental issues affect scheduling making it a challenging endeavor. These aspects were presented in a framework in the Section 3.3.1 on literature synthesis, where scheduling was combined with project management. A variety of factors should be taken into account when formulating a schedule, including the management actions during schedule construction and schedule implementation. However, all factors which interact with and affect scheduling could not be included in this study.

One difficult aspect in project scheduling is to manage and control people performing the projects. Human nature poses difficulties which work against delivering projects on time. The student syndrome became a well-known flaw of each person during this study. Incorporating the project-related uncertainty to schedules is especially challenging. Project management practitioners have realized that the development of a perfect project schedule is a myth due to the lack of accurate data on project task durations. Uncertainty also affects optimization simulations because the input data are merely estimates. Quantum mechanical wave functions are used in Planalyzer to model these uncertainties of human productivity.

In practice, most schedules are created according to the "good enough" principle because of the cost-time trade-off of projects. In fact, exact schedule information is impossible to get and the schedule will always updated and changed during the project implementation. In striving for a complete and realistic schedule, the costs and time escalate much more than the achieved benefits.

In the beginning of the research, it was understood that if the evaluation of schedule quality is to be concluded, the methodology must be simple and robust. Complex scheduling methods have not become popular in daily project management because of their time requirements for usage. Planalyzer seemed to be a potential approach for schedule evaluation, but the currently developed schedules of case companies were not fulfilling the prerequisites for analysis. However, one schedule could be analyzed and the results of Planalyzer analysis were interesting.

In comparison with the conventional critical path analysis, Planalyzer indicated the same prioritized tasks as in the critical path. If those tasks are exposed based on a quantum mechanical model without critical path calculations, the method could be used in the analysis of large and complex schedules. Based on the findings above, it can be also argued that Planalyzer provides no new information because the critical path tasks can be indicated with the CPM. However, Planalyzer ranks the tasks based on their importance and provides probabilities of milestones which cannot be easily indicated with conventional methods.

Empirical research of scheduling practices in four case companies indicated clearly that using professional schedulers leads to better schedule quality. However, it could not be proved that projects with quality schedules are more successful than those with lower quality. Overall, the scheduling practices seemed to be quite similar in the case companies, except one case company which was using additional Excel-based plans together with a scheduling software tool. Schedules were not evaluated in the companies and systematic collection of post-project schedule based information was rare. All case companies were using schedules of previous projects when formulating new schedules. These practices are proposed to be one of the reasons why improvements are not diffusing into daily project management practices.

Planalyzer as well the criteria of the suggested evaluation framework concentrate mainly on the structure of schedules. Well-established schedule structure is important, but the content of the schedule is crucial. The content, however, can only be assessed through deep know-how of the project-specific processes. Thus, the suggested criteria for evaluating schedule quality and the developed checklist can mainly be used as a managerial tool as well as a model for organizations to develop schedule quality and focus attention on project scheduling pitfalls. The proposed framework and checklist can be utilized to developed schedules to such a level that they can be adapted for Planalyzer evaluation.

Finally, it must be realized that neither conventional scheduling methods nor suggested models or Planalyzer can address the most profound problems of project management. They can not fully explain why projects last longer than scheduled and cost more than planned, but they can be used to enhance the scheduling process and make sure schedules are as good as possible.

5.1 Contributions and Applicability

The main contributions of this study are the frameworks presented for schedule evaluation and the literature review on the current state of scheduling practices. Although Planalyzer is considered a handy tool for schedule assessment, the schedules were not suitable for analysis due to lack of fundamental schedule information, which is also essential for CPM.

Even though the framework of schedule quality evaluation was developed for industrial EPC delivery projects, it should be applicable to other projects also. Generally project schedules are constructed in a similar manner, hence, they could be evaluated with the suggested model. The only requirements for Planalyzer are the MS Project format and enough dependency connections in the schedule. Consequently, schedules from different fields or industries can be subjected to the assessment presented. As a general model, the frameworks presented and Planalyzer are not associated with any particular industry and can be generalized without much effort.

In many cases it is impossible to assess the quality of schedules without basic knowledge of the considered project. Analyzing only the structure of a schedule does not reveal all aspects of schedule quality if the reliability of input information is not known.

When applying the results of this study in other schedules and projects the possible bias from industrial delivery projects should be taken into account. This study can act as a starting point for developing current schedules, but some of the assumptions in the evaluation framework have to be confirmed by conducting more studies on how well it can be used for schedule evaluation.

5.2 Reliability of the Study

A wide variety of sources were used in the literature study about project scheduling. The historical insight should be treated with caution because it is mainly from only two sources. Scheduling methods and processes as well as the use of scheduling software tools are described extensively in literature, thus, the results for those parts are quite reliable.

Literature considering schedule evaluation was virtually non-existent. The framework in the synthesis following the literature study is largely compiled from different sources of reviewed literature. As the schedule assessment processes have not been studied before, no relevant material about the subject could be found.

Although the features of Planalyzer were described extensively, all studied information was provided by the company (Ibico) which created the software. The code of computation logic was not scrutinized due to reasons of confidentiality, so the software can be seen in many parts as a black box. There is no certainty of how the calculations are performed.

The reliability of the interviews can be questioned because only four cases were studied and only one person of each company (except in the case of Case Company C) was interviewed. All interviews were conducted in the same way, and almost all the same questions were asked. Interviewees of Case Company C included one manager of the project service department and two project engineers specialized in scheduling. In other case companies the interviewees were either project managers or schedulers. It should be noted that some interviewees were more experienced than others. Some had better views of the entire project, which can facilitate the whole scheduling process. It is also worth notice that in three case companies the interviewees were chosen by the case company representatives.

The framework and checklist finally suggested were not used in practice, thus they should be tested with real projects to verify their usefulness, as suggested in the next section.

5.3 Opportunities for Further Research

Based on the findings in this study it would be interesting to use the evaluation framework suggested and checklist in a case study to assess their feasibility in scheduling. Based on the results, the framework and checklist could be further developed and different kinds of lists could be created for different schedules. Furthermore, the development of a systematic procedure for measuring schedule quality criteria could be investigated.

Further research on the Planalyzer method would be useful and require in-depth analysis of the calculation logic of the software. The alpha test version of Planalyzer-2 had just been released and it would have been interesting to see if the results were different. If the case companies had included all of the dependencies between tasks, the schedules could be analyzed without any additional work. Evaluation of schedules which include thousands of tasks is almost impossible without automated software tools, so the Planalyzer-2 would provide needed assistance.

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7 Appendices

Appendix A Critical success factors developed in literature

Martin (1976)	Locke (1984)	Cleland and King (1983)	Sayles and Chandler (1971)	Baker, Murphy and Fisher (1983)	Pinto and Slevin (1989)	Morris and Hough (1987)
Define goals	Make project commitments known	Project summary	Project manager's competence	Clear goals	Top management support	Project objectives
Select project organizational philosophy	Project authority from the top	Operational concept	Scheduling	Goal commitment of project team	Client consultation	Technical uncertainty innovation
General management support	Appoint competent project manager	Top management support	Control systems and responsibilities	On-site project manager	Personnel recruitment	Politics
Organize and delegate authority	Set up communications and procedures	Financial support	Monitoring and feedback	Adequate funding to completion	Technical tasks	Community involvement
Select project team	Set up control mechanism (schedules, etc.)	Logistic requirements	Continuing involvement in the project	Adequate project team capability	Client acceptance	Schedule duration urgency
Allocate sufficient resources	Progress meetings	Facility support		Accurate initial cost estimates	Monitoring and feedback	Financial contract legal problems
Provide for control and information mechanism		Market intelligence (who is the client)		Minimum start-up difficulties	Communication	Implement problems
Require planning review		Project schedule		Planning and control techniques	Trouble-shooting	
		Executive development and training		Task (vs. social orientation	Characteristics of the project team leader	
		Manpower and organization		Absence of bureaucracy	Power and politics	
		Acquisition			Environment events	
		Information and communication channels			Urgency	
		Project review				

(Belassi and Tukel, 1996)

Appendix B Introduction of the Study for Case Companies

Master's Thesis about Project Scheduling

I am doing my Master's thesis about the quality of project schedules in industrial projects (supervised by Professor Karlos Artto). The thesis is a part of research project in Global Project Strategies II research programme in the Project Business Group at Helsinki University of Technology. Thesis consists of literature review and empirical study. The empirical part concentrates on case projects and to a new method called Planalyzer. Planalyzer is an add-on feature for Microsoft Project and it provides quantitative assessment of project milestones. The method defines the quality of project schedules in terms of probable success, and tries to predict the impact of task slippage on planned milestones. It suggests how the project schedule has to be modified to make it reasonable.

Objectives of the thesis are:

- Understand the current state of project scheduling
- Define the characteristics of good project schedules
- Find out how to evaluate the quality of schedules
- Find analytical methods and tools to assess schedules
- Find out how Planalyzer evaluates the quality of project schedules

Global Project Strategies II is a research programme focusing on managerial challenges. The aim of the programme is to develop new ways to manage effectively and innovatively risks in global projects. GPS II is a joint effort by three Finnish research institutions: Helsinki School of Economics, Helsinki University of Technology, and VTT. The programme is executed in a close collaboration with the participating companies and the Collaboratory for Research on Global Projects (CRGP) at Stanford University.

The focus of GPS II is on the existing global project strategies and risk management of Finnish firms and that is why I would be very thankful if Your Company could provide the required information to support my thesis work.

Non-disclosure agreements (NDA) will be provided by Helsinki University of Technology if needed.

If you have questions related to the study, please contact:

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Appendix C Interview Outline

Perustiedot ja aikataulut koskien tapausprojektia toimitettu ennen haastattelua.

- Mitä eri aikatauluja käytetään?
- Mihin aikatauluja käytetään? Funktiot?
- Kenelle aikatauluja tehdään? Käyttäjät, sidosryhmät?
- Koska eri aikataulut tehdään, miten päivitetään?
- Kuka tekee? Alihankkijat?
- Tehdäänkö viikkoaikatauluja?
- Mitä ohjelmia tai ohjelmistoja käytetään?
- Tiedetäänkö mihin ohjelman toiminta perustuu?
- Voidaanko aikataulua muuttaa toteutuksen aikana?
- Käytetäänkö jotain tiettyä metodia tai menetelmää aikataulujen laatimiseen?
- Kuinka tehtävien kestot on arvioitu? Asiantuntija-arviot, projektiryhmät, hihasta?
- Onko dataa kerätty aikaisemmista projekteista?
- Kuinka riippuvuudet on määritelty?
- Käytetäänkö buffereita, jos kyllä, niin miten ne on määritelty?
- Miten vältytään piilopelivaroilta?
- Onko resurssit otettu huomioon aikataulua laadittaessa?
- Onko projektit kuinka ainutlaatuisia? Miten vaikuttaa aikataulutukseen?
- Onko Critical Chain tai Theory of Constraints tuttu?
- Tekevätkö projektityöntekijät tai projektipäällikkö monia projekteja samaan aikaan?
- Mitenkä työntekijät sitoutetaan toteuttamaan aikataulua?
- Palkitaanko työntekijä tai alihankkija, jos tehtävä valmistuu etuajassa?
- Miten kotimaan ja ulkomaiden aikataulut eroavat toisistaan?
- Onko joitain tilanteita, joissa on ollut ongelmia aikatauluissa?
- Mitkä ovat virheitä tai heikkouksia aikataulussa? Karkeat tehtäväerittelyt, pelivarojen puute, piilopelivarat, sitoutumisen puute?
- Arvioidaanko tehtyjä aikatauluja jotenkin ennen toteutusta?
- Arvioidaanko toteutuksen aikana?
- Arvioidaanko projektin päätyttyä kuinka hyvin aikataulu toteutui?
- Mitä aikataulun laatu tai hyvyys merkitsee?
- Miten kuvailisit hyvää aikataulua?
- Koetteko, että aikatalutus on tällä hetkellä yrityksessänne hyvällä mallilla, vai onko jotain parannettavaa?

Appendix D Checklist

Ser.No.		Yes	No	Comments
A	**GENERAL**			
1	Has the project team been involved in the scheduling from the beginning of the schedule development?			
2	Have subcontractors and suppliers been involved?			
3	Have the schedules been organized in hierarchy levels?			
B	**ACTIVITY DEFINITION (activity = task)**			
1	Have the scheduled tasks been decomposed from WBS work packages?			
2	Is the time scale consistent throughout the schedule (days, weeks or months)?			
3	Have tasks been limited to measurable and controllable results?			
4	Have all tasks been described uniquely (clear and understandable names)?			
C	**ACTIVITY SEQUENCING**			
1	Has the sequencing of tasks been done according to construction practices?			
2	Have dependencies between tasks been identified?			
3	Have all tasks at least one successor and one predecessor?			
4	Has the use of start-to-finish relationship been avoided?			
5	Is the structure of the schedule clear and logical?			
6	Have all applicable milestones been identified in the schedule?			
D	**ACTIVITY RESOURCING**			
1	Have resources been included in the schedule?			
2	Have appropriate personnel and equipment been assigned to all tasks?			
3	Has every task at least one responsible person (task owner)?			
4	Have all non-working times (individual, company, public, non-working holidays, etc.) been taken into account?			
5	Has the availability of all non-full-time workers for this project (due to other projects, etc.) been taken into account?			
E	**ACTIVITY DURATION ESTIMATING**			
1	Has the work effort of each task been estimated realistically?			
2	Have durations been compared to actual durations from past projects?			
3	Have expert opinions been taken into account?			
4	Have project team members agreed upon and committed to task estimates?			
5	Do the scheduled tasks have an appropriate level of detail (max 10% of total project duration)?			
6	Has the uncertainty been assessed for more risky tasks?			
7	Have the buffers been estimated realistically?			
8	Have optimistic and pessimistic estimates of durations been done?			
9	Has the inclusion of buffers into duration estimates been avoided?			
10	Have the buffers been set in the right places?			
F	**OUTSOURCING/SUBCONTRACTORS**			
1	Have subcontractors' parts been added to the schedule?			
2	Have subcontractors' parts been reviewed?			

(Continued on next page)

G	**APPROVALS**			
1	Has the critical path been identified?			
2	Has the baseline schedule been made and approved?			
3	Has the project manager approved the schedule?			
4	Has the project team approved the schedule?			
5	Has the client approved the schedule?			
6	Have project stakeholders / subcontractors approved the schedule?			
H	**SCHEDULE CONTROL**			
1	Will the schedule be presented visibly?			
2	Will the realization of the schedule be recorded?			
3	Will the actual efforts and dates be followed weekly?			
4	Will the schedule be updated weekly? How? By whom?			
5	Will the revised schedule be distributed in electronic format to all stakeholders?			
6	Will the lessons learned be applied at the end of each project phase?			
		Yes (%)	**No (%)**	
	SUMMARY			